Unveiling the cosmic web through Lyα emission: from MUSE to WST

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Università degli Studi di Milano Bicocca

European Research Council
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ΛCDM COSMOLOGICAL PARADIGM

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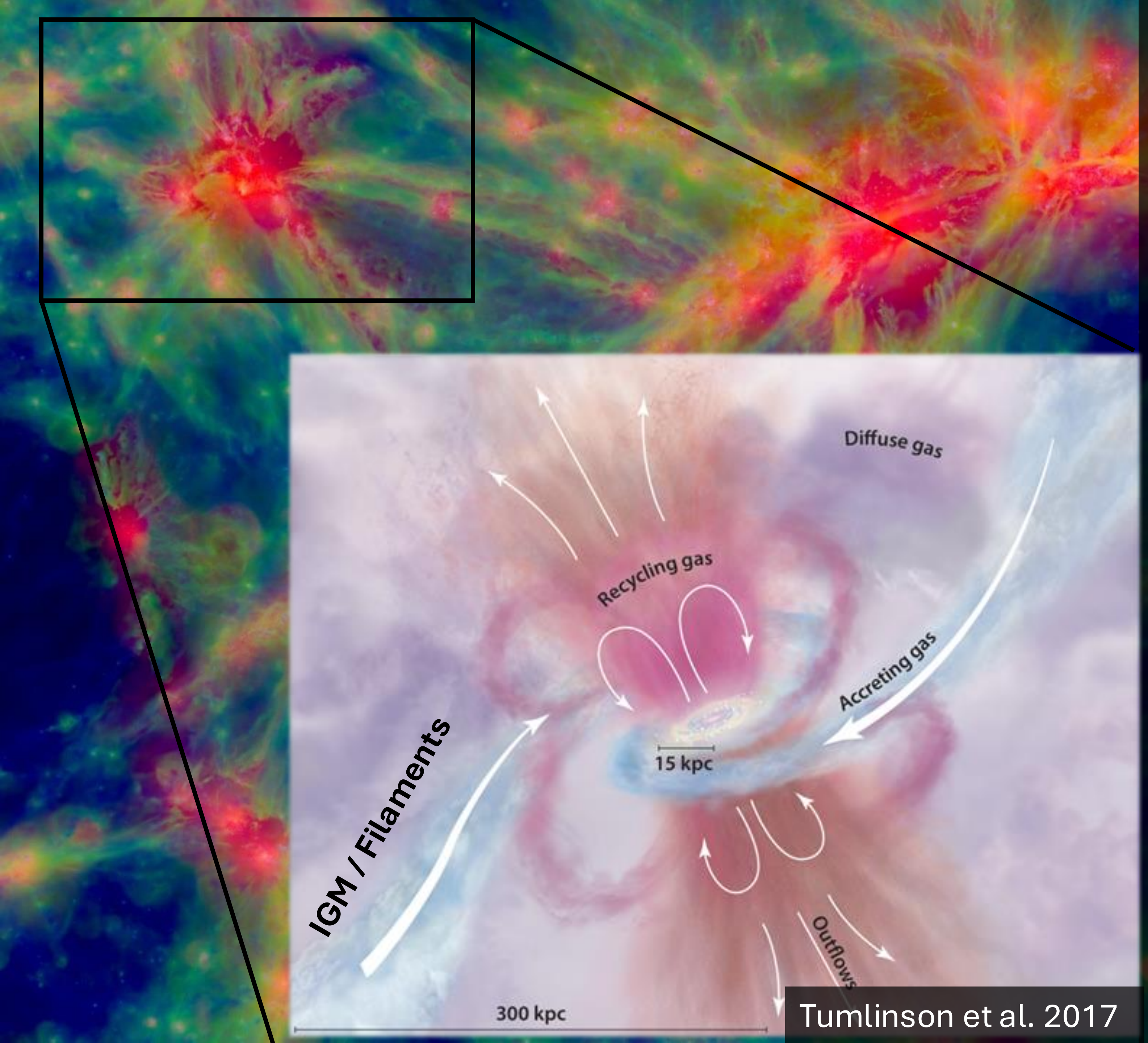
FILAMENT-DOMINATED STRUCTURE ON LARGE SCALES: «THE COSMIC WEB»

EAGLE simulation; Schaye et al. 2015



FILAMENTS FEED THE CGM THAT REGULATES THE GAS EXCHANGE BETWEEN GALAXIES AND THE SORROUNDING IGM

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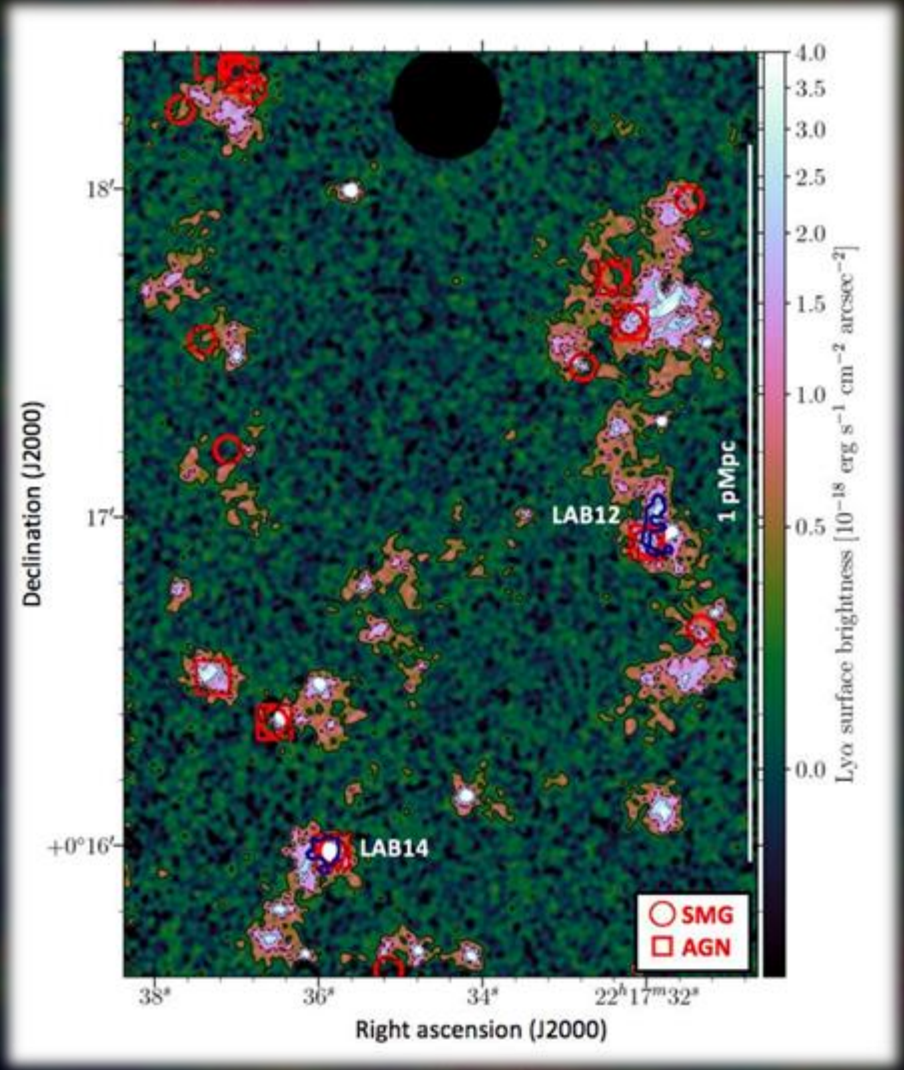
CONTROLS THE GALAXY GROWTH THROUGH COSMIC TIME

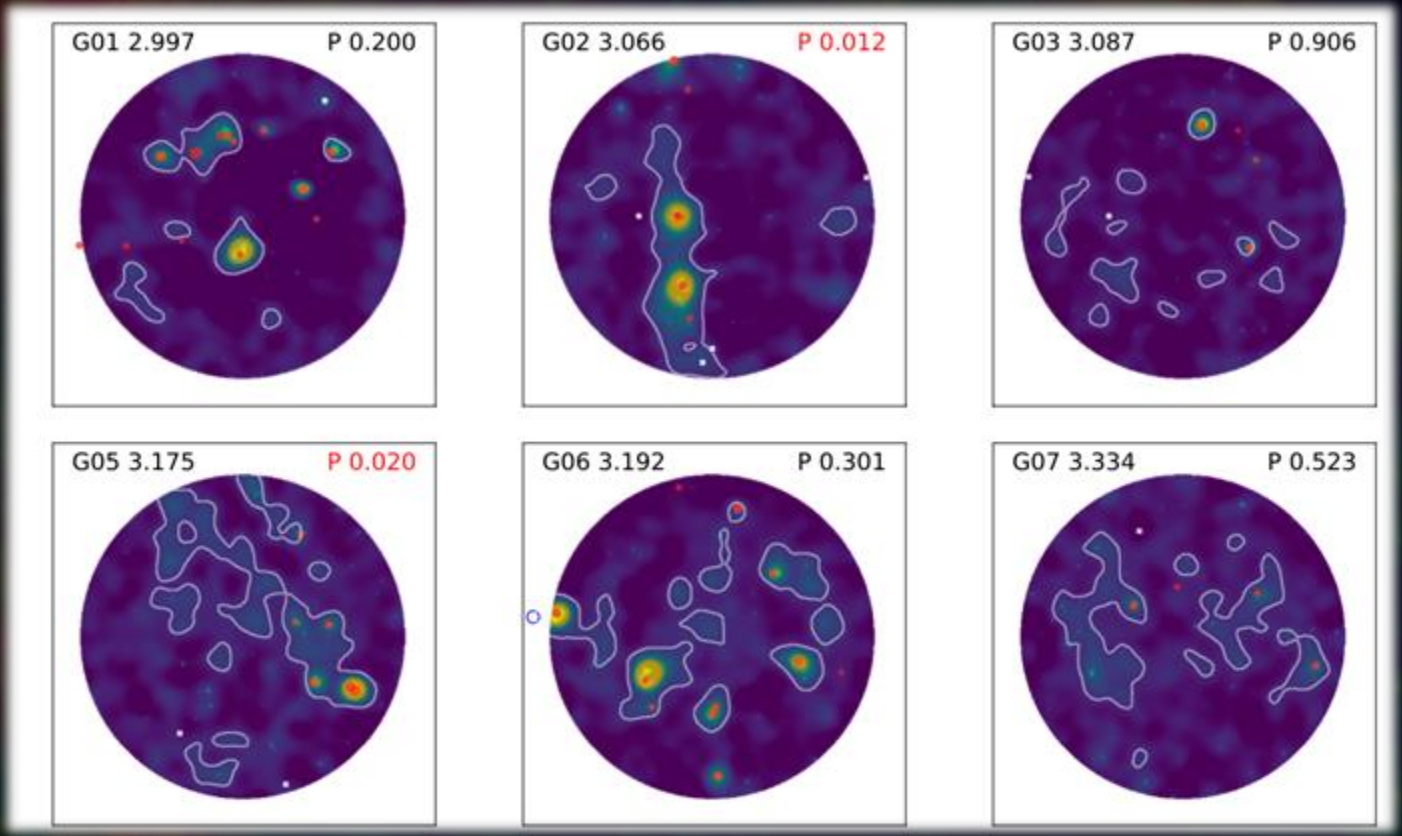
GENERAL GOAL:

Study the properties of the large scale structures (filaments) and the link between galaxies and their circum/inter galactic medium at $z \approx 3 - 4$

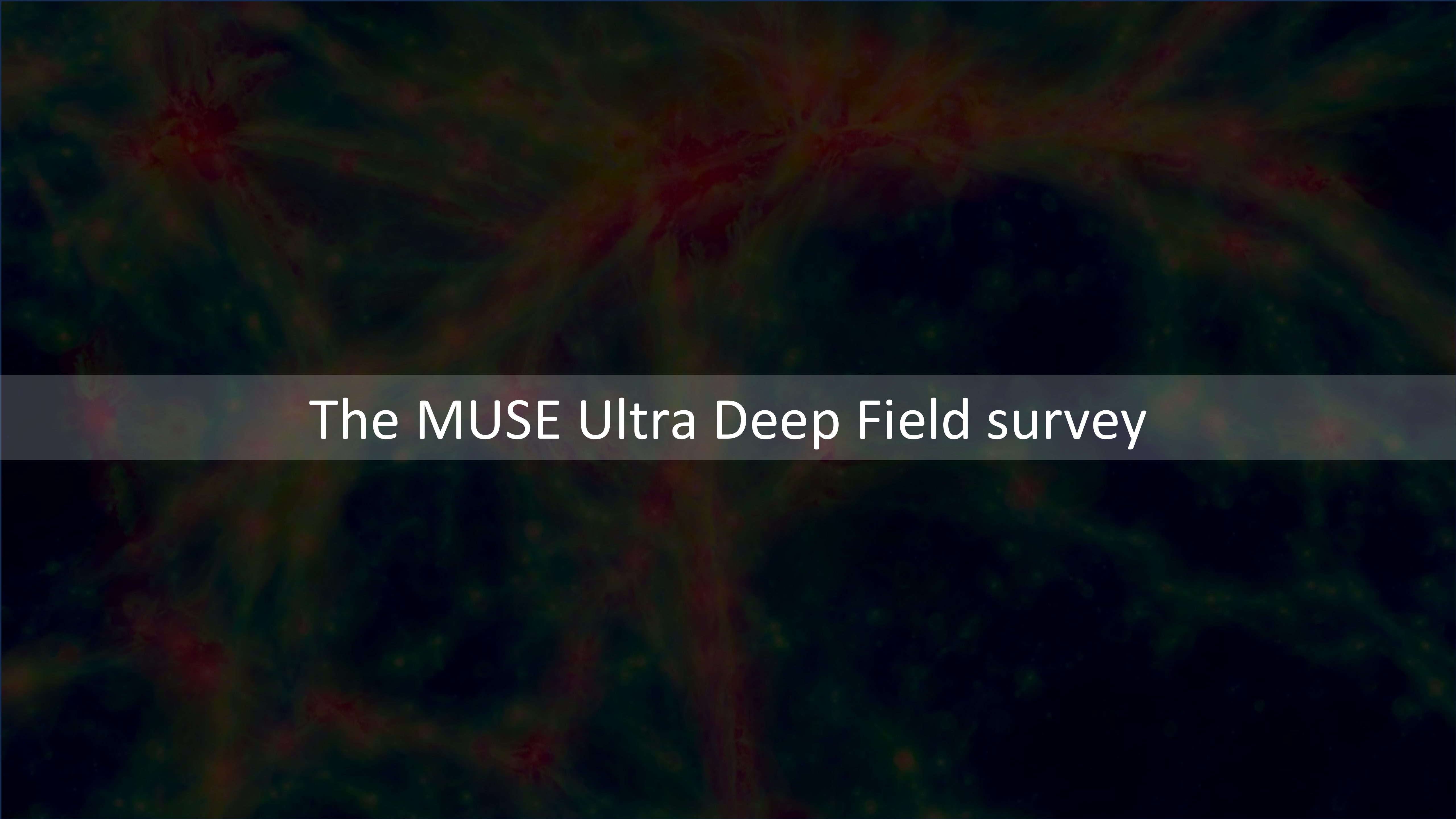
The Cosmic Web in emission: some examples



SSA22 – Umehata et al. 2019



MXDF – Bacon et al. 2021


The MUSE Ultra Deep Field survey

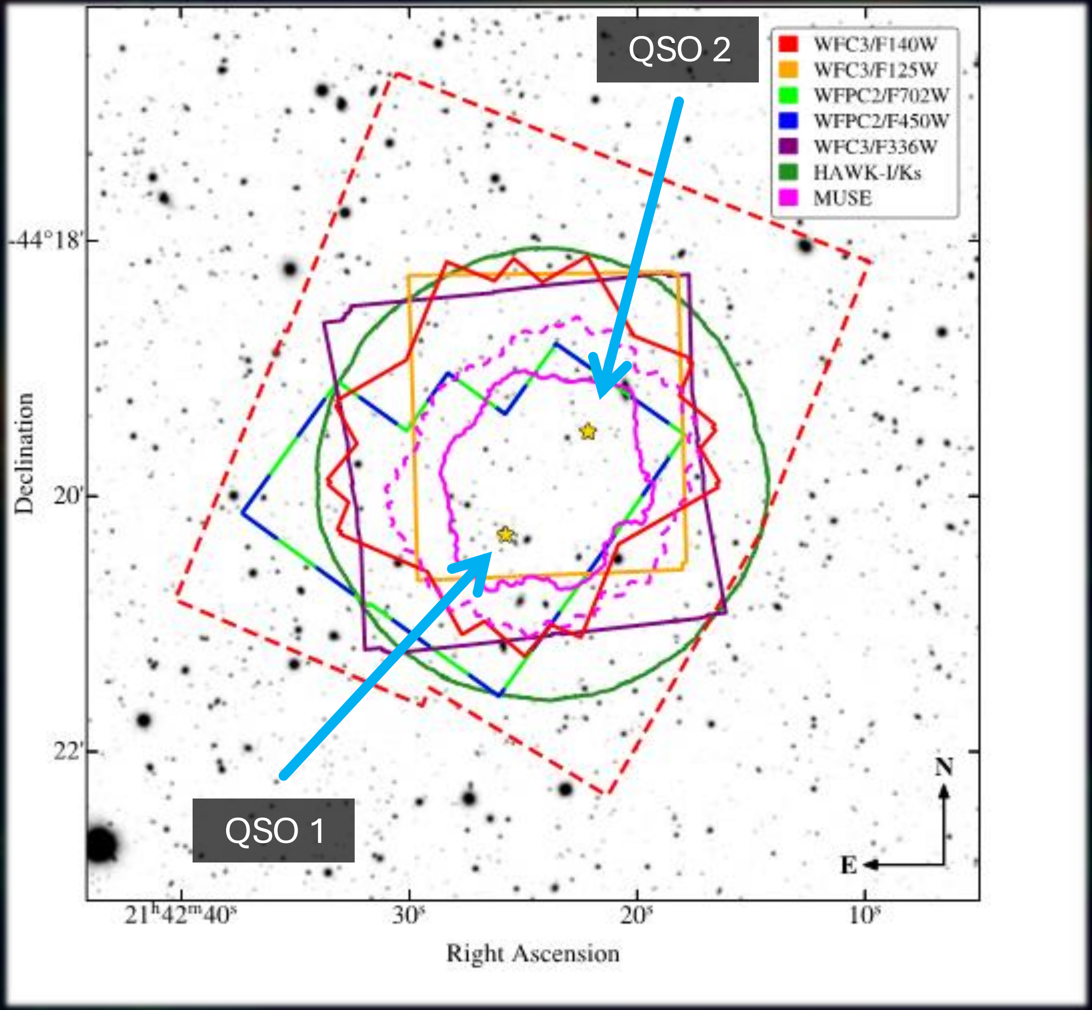
The MUSE Ultra Deep Field (MUDF)

ONE OF THE KEY GOALS:

image the Lyα emission from two massive nodes at $z \approx 3.22$

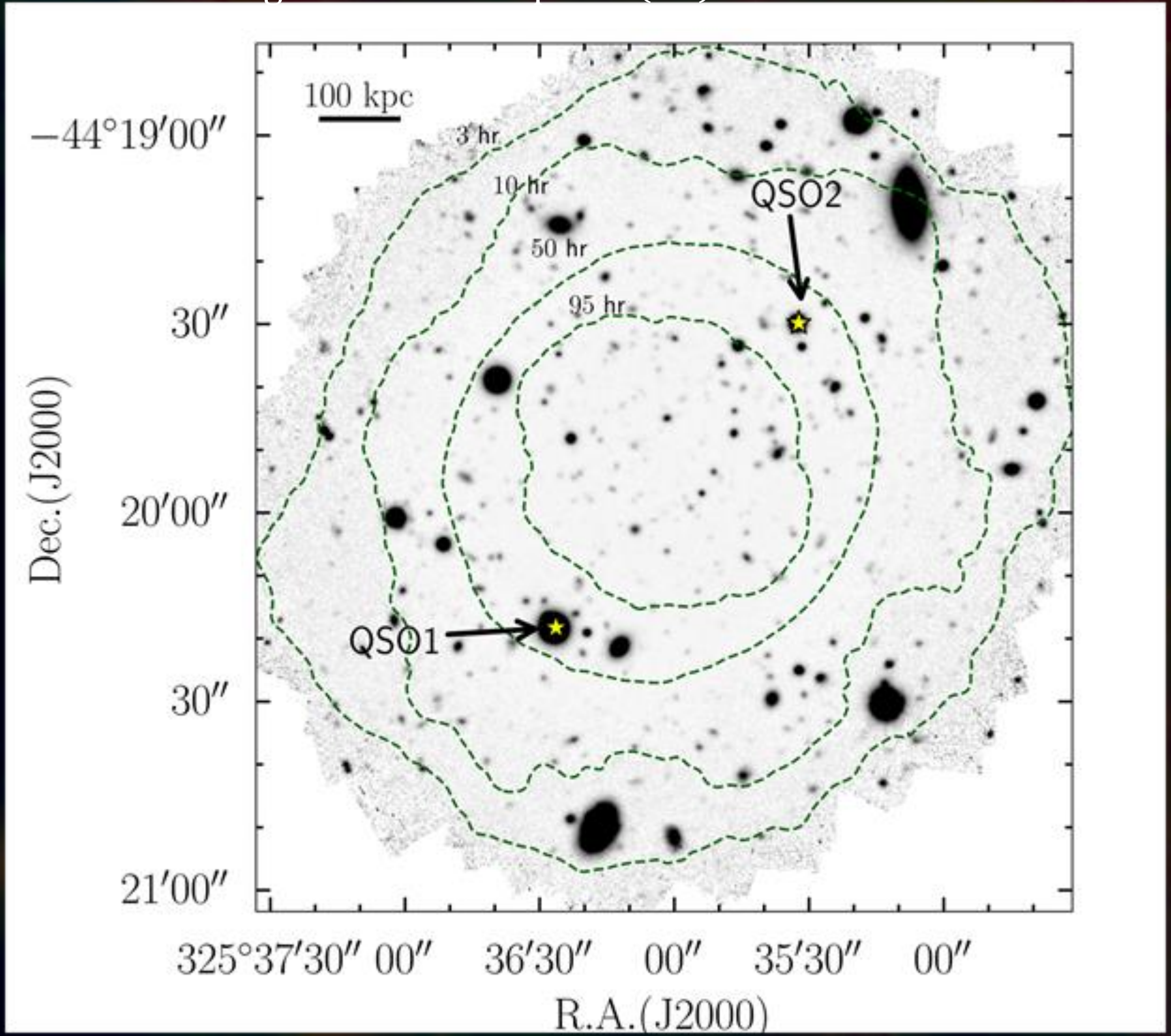
Observations:

- **142h** MUSE (PI Fumagalli) similar to the MUSE GTO MXDF;
- 90 orbits HST WFC3 G141 spectroscopy ;
  + F125W, F140W imaging (PI Rafelski);
- 8 orbits HST UV imaging (PI Fossati);
- 30h UVES QSO spectroscopy (PI D’Odorico);
- 27h HAWK-I K-band imaging (PI Fossati);
- ALMA Band 3 and 6 programs (PI Fumagalli, Pensabene).



The environment of the QSO pair

Full dataset rms = 3×10^{-21} erg s^{-1} cm^{-2} Å^{-1} pix^{-1} (1σ)



D. Tornotti et al., 2024, *Nature Astronomy*

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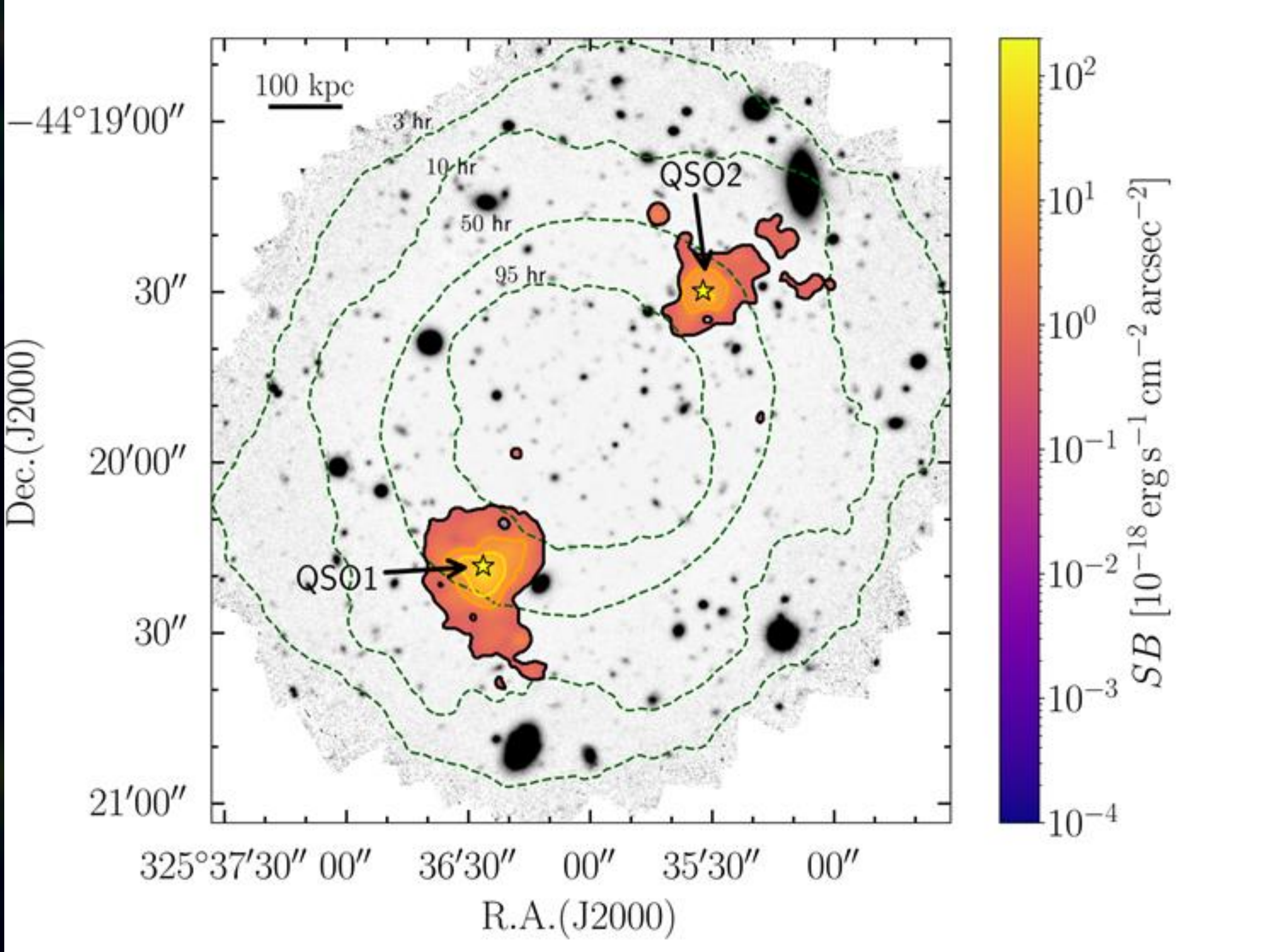

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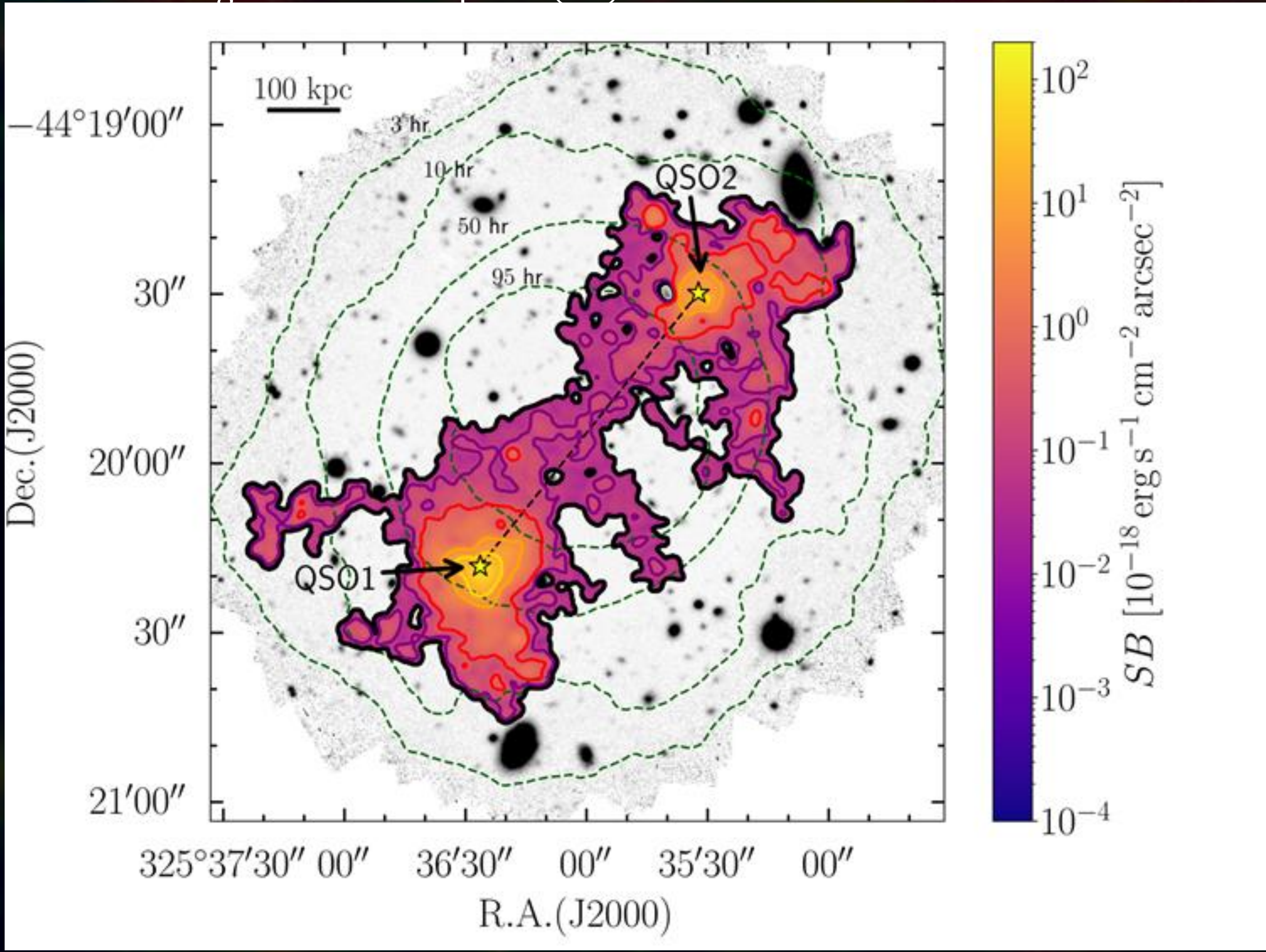

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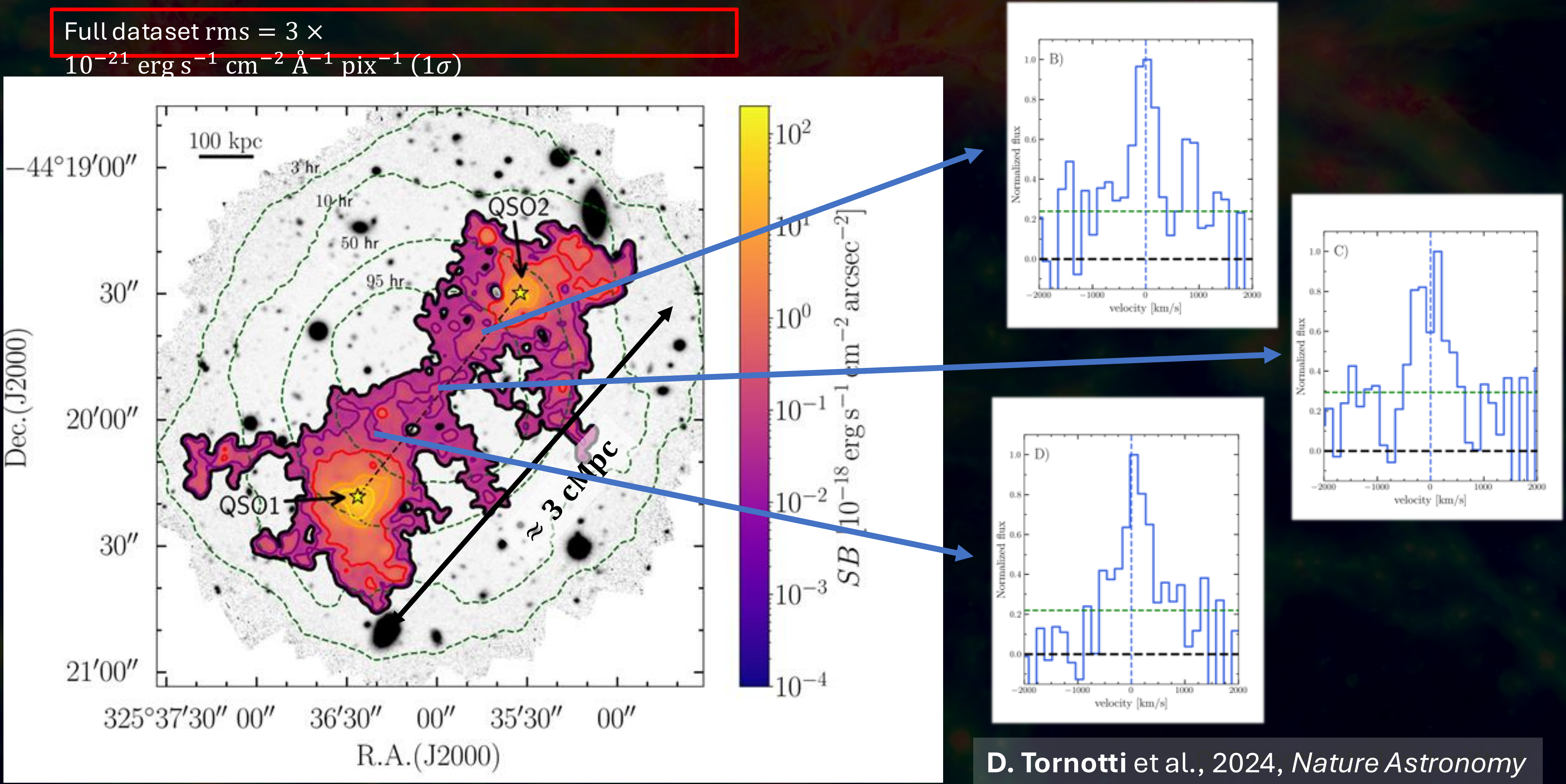

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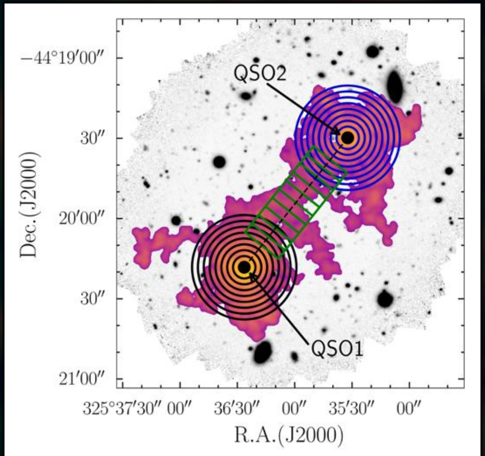
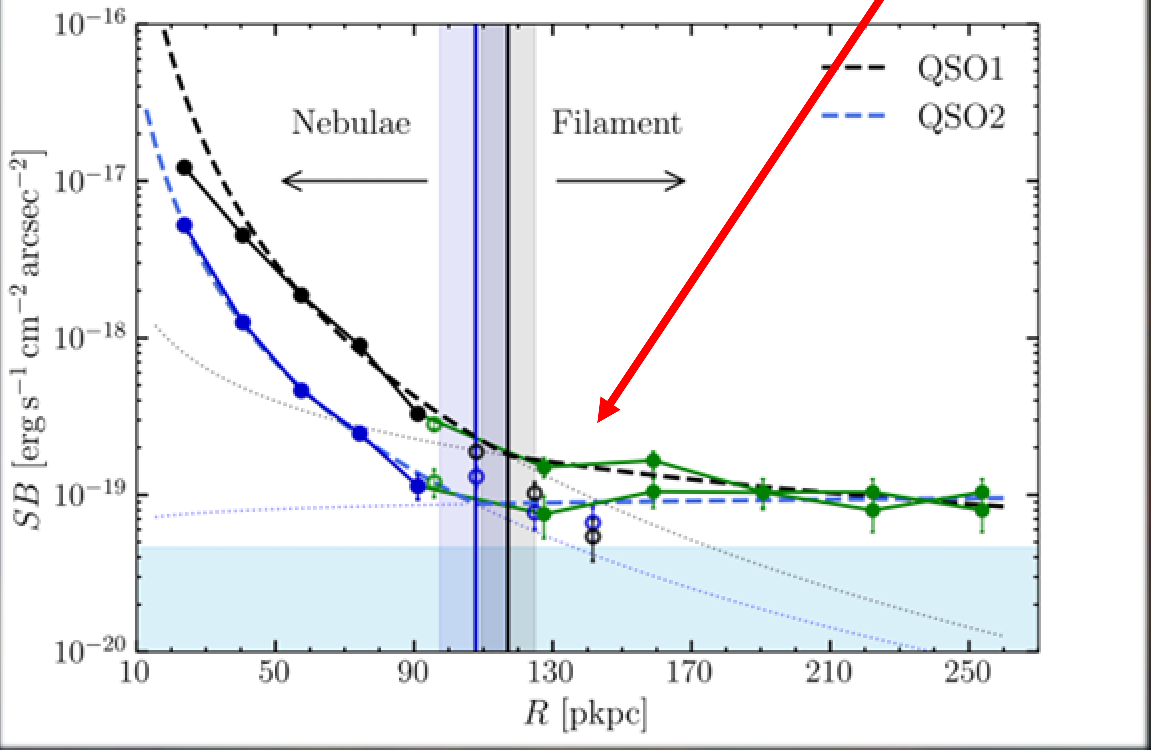


e.g. Fossati et al 2021,
de Beer et al 2023

$R_t \approx 100$ pkpc

Profile *along* the filament



Profile *perpendicular* to the filament

D. Tornotti et al., 2024, *Nature Astronomy*

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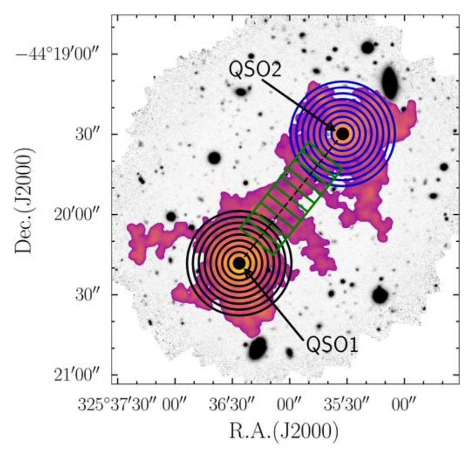

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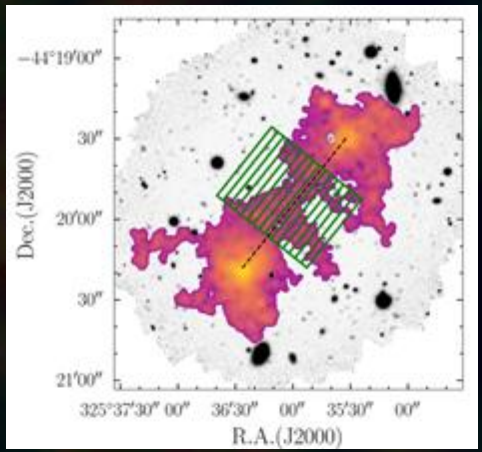

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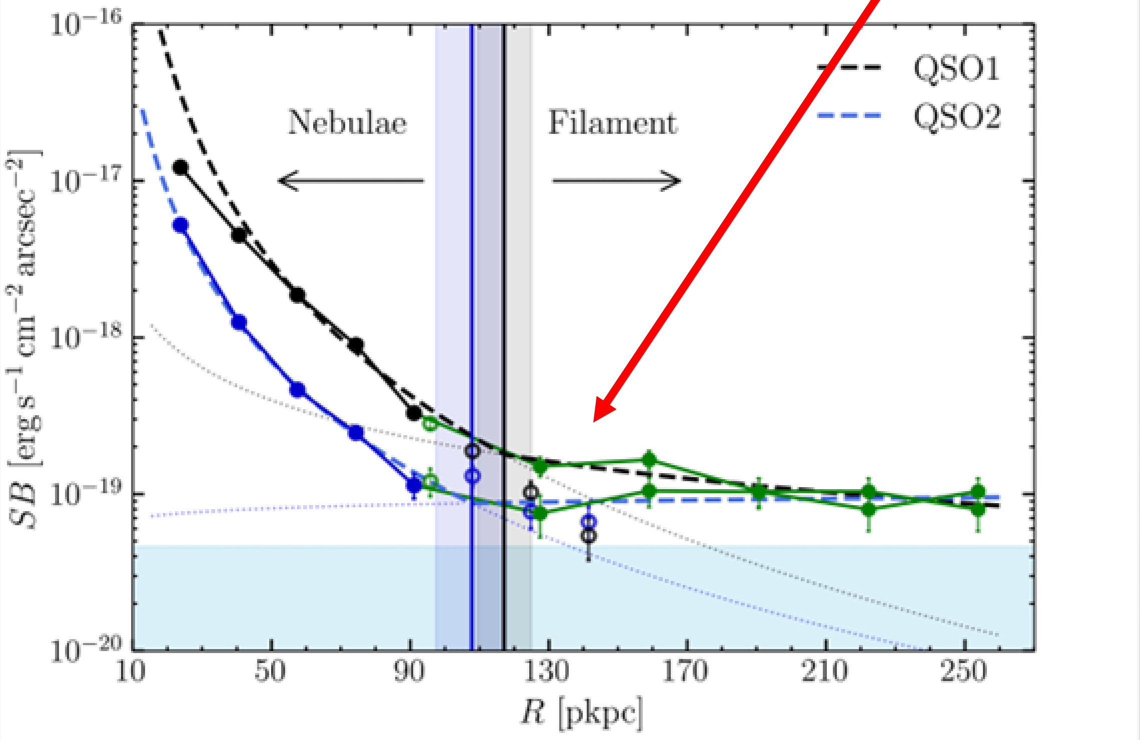

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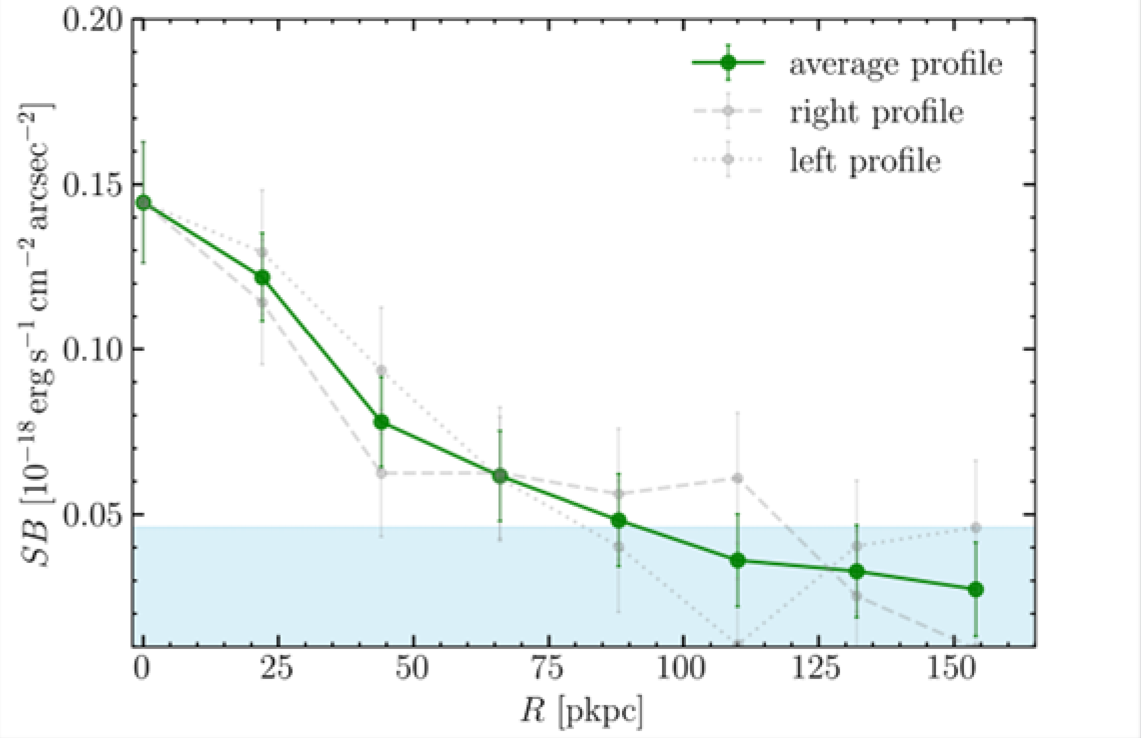


D. Tornotti et al., 2024, *Nature Astronomy*

The environment of the QSO pair

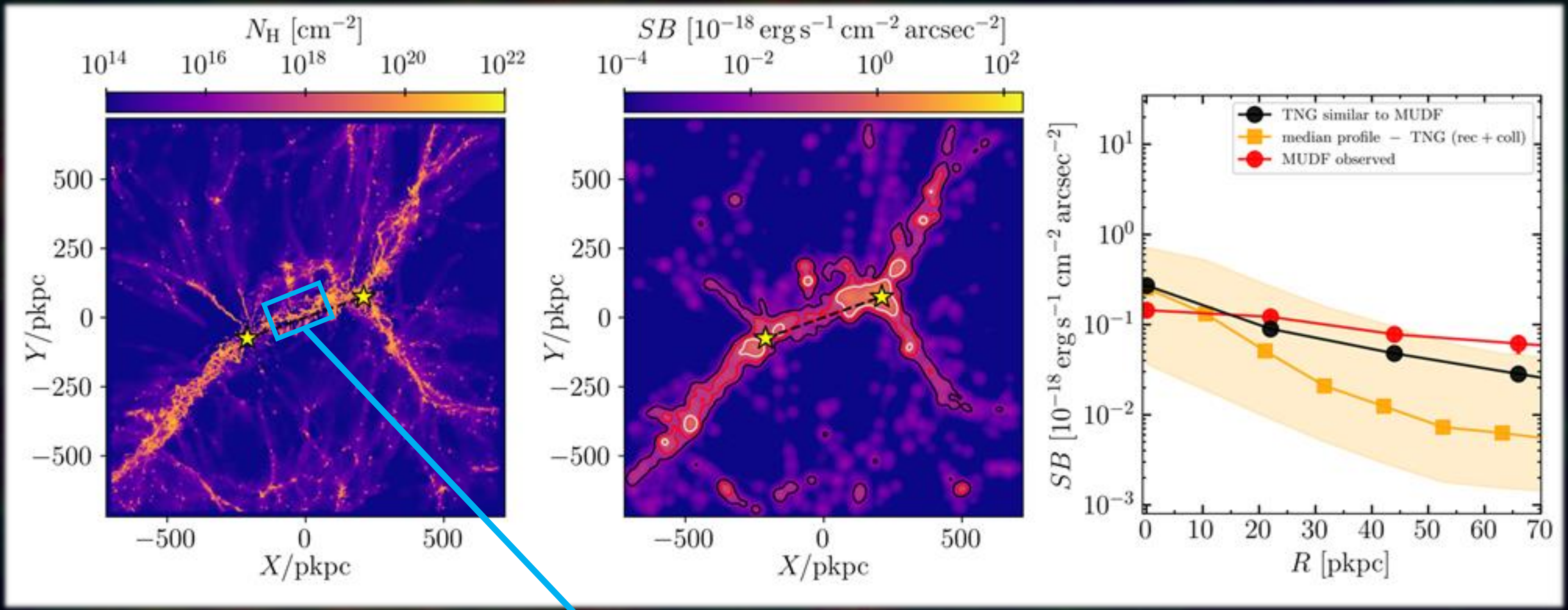
QSO1: $\log\left(\frac{M_h}{M_\odot}\right) = 12.9 \pm 0.3$

QSO2: $\log\left(\frac{M_h}{M_\odot}\right) = 12.2 \pm 0.4$

From L-Galaxies SAM with advanced QSO recipes (Izquierdo-Villalba et al. 2020)

L - GALAXIES

Comparison with TNG-100



$n_H^{IGM} \approx 10^{-3}\ \mathrm{cm}^{-3}$

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LAEs overdensities in the MUDF

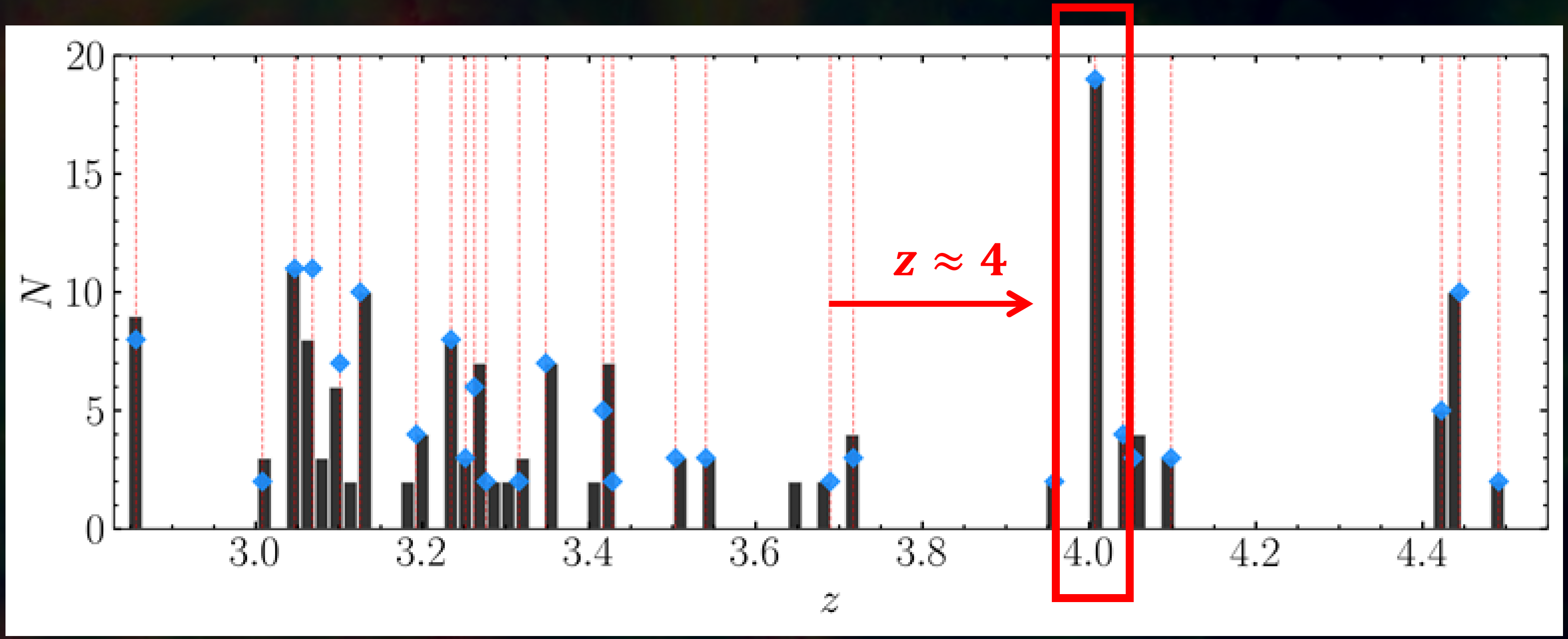
LAEs overdensities in the MUDF

Lyman-alpha emitters (LAEs): young , star forming and low mass galaxies showing Lyα emission line in their spectra.

Step 1: Catalogue of LAEs in the MUDF (more than 200 LAEs spectroscopically confirmed);

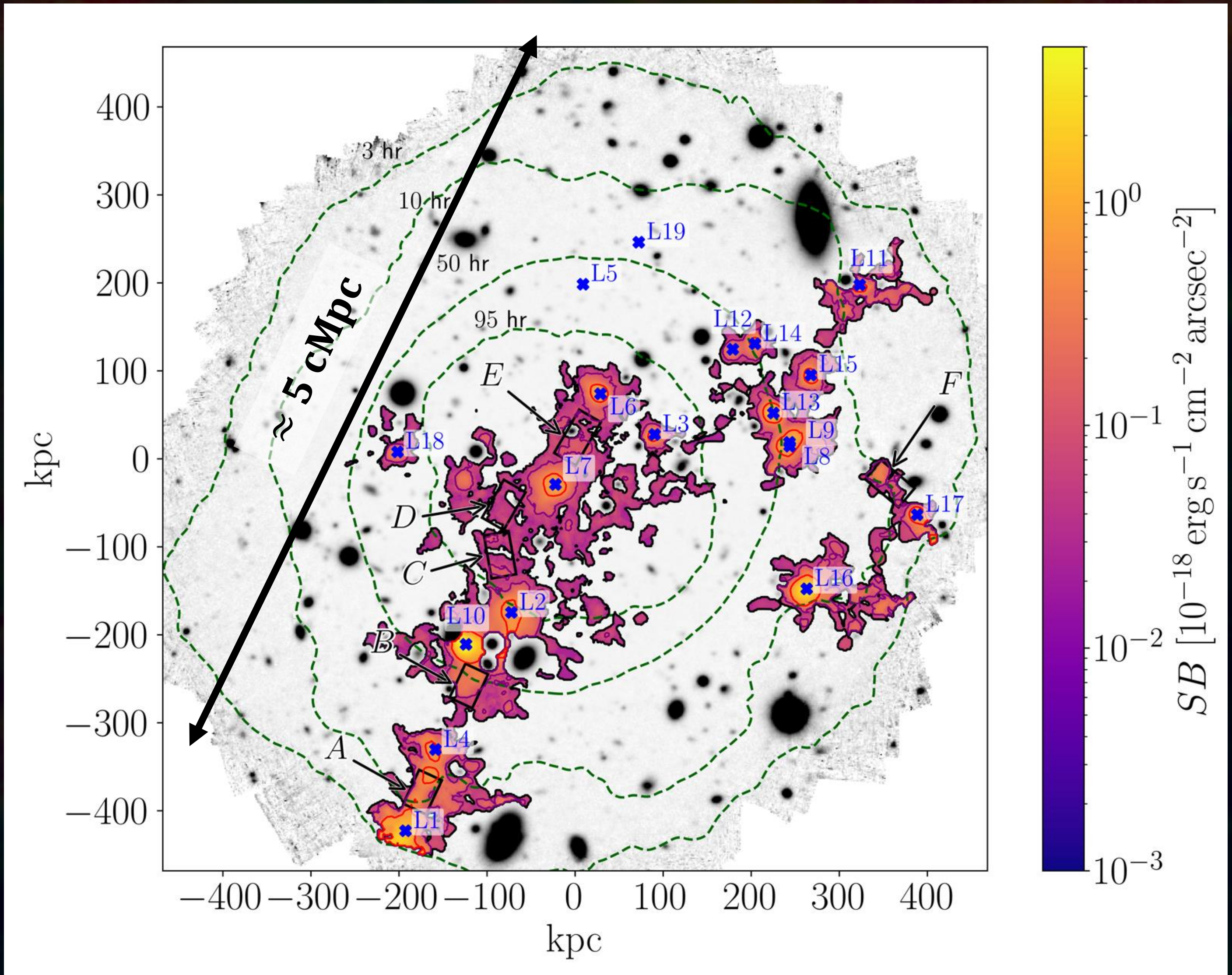
Step 2: Define overdense regions of LAEs (up to ~ 25);

Step 3: Search for extended Lyα emission tracing filamentary structures.



D. Tornotti et al. in preparation

Filaments around LAEs at z~4



New extraction code:

SHINE

10.5281/zenodo.14710518

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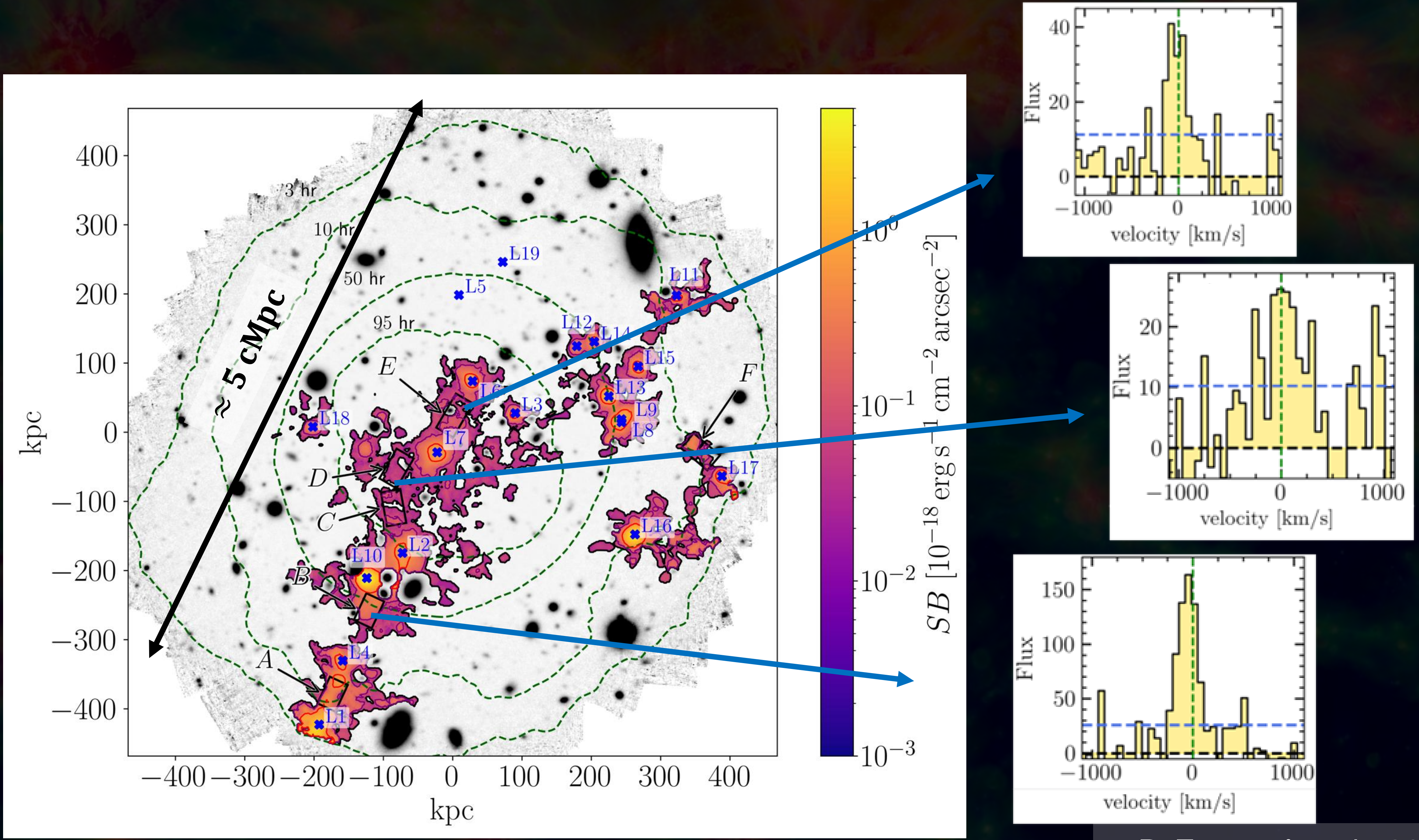
Filaments around LAEs at z~4



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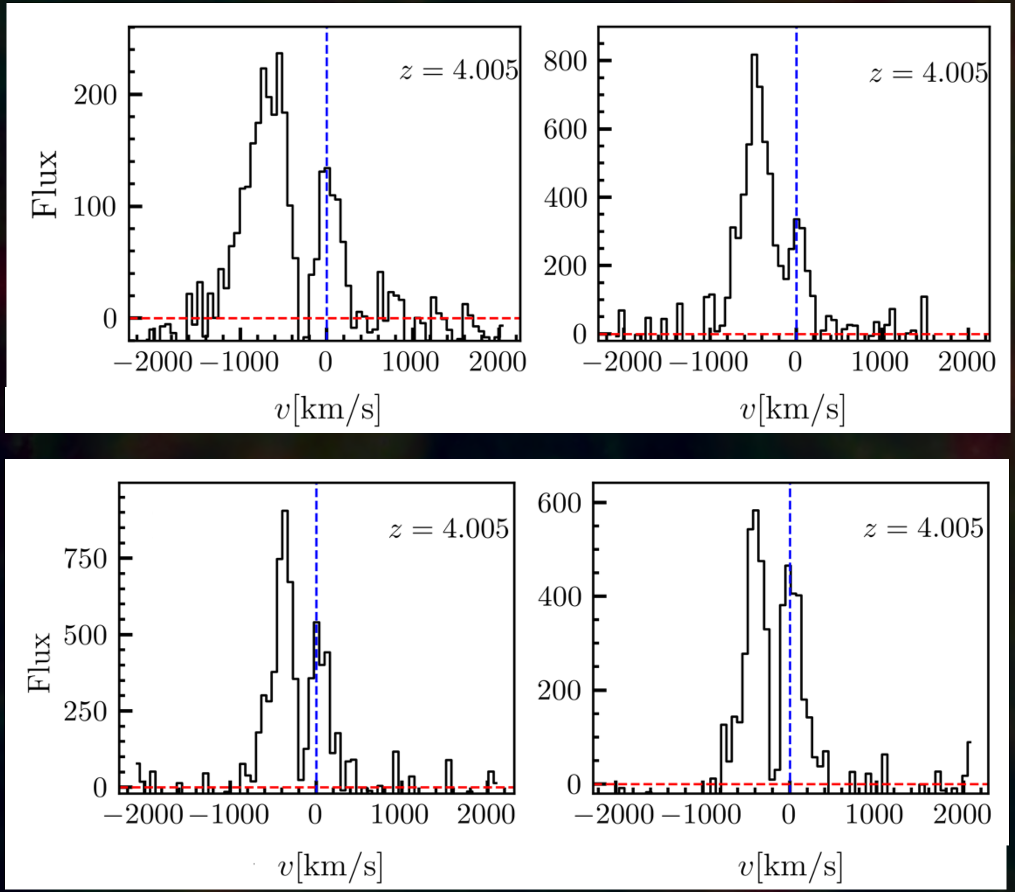
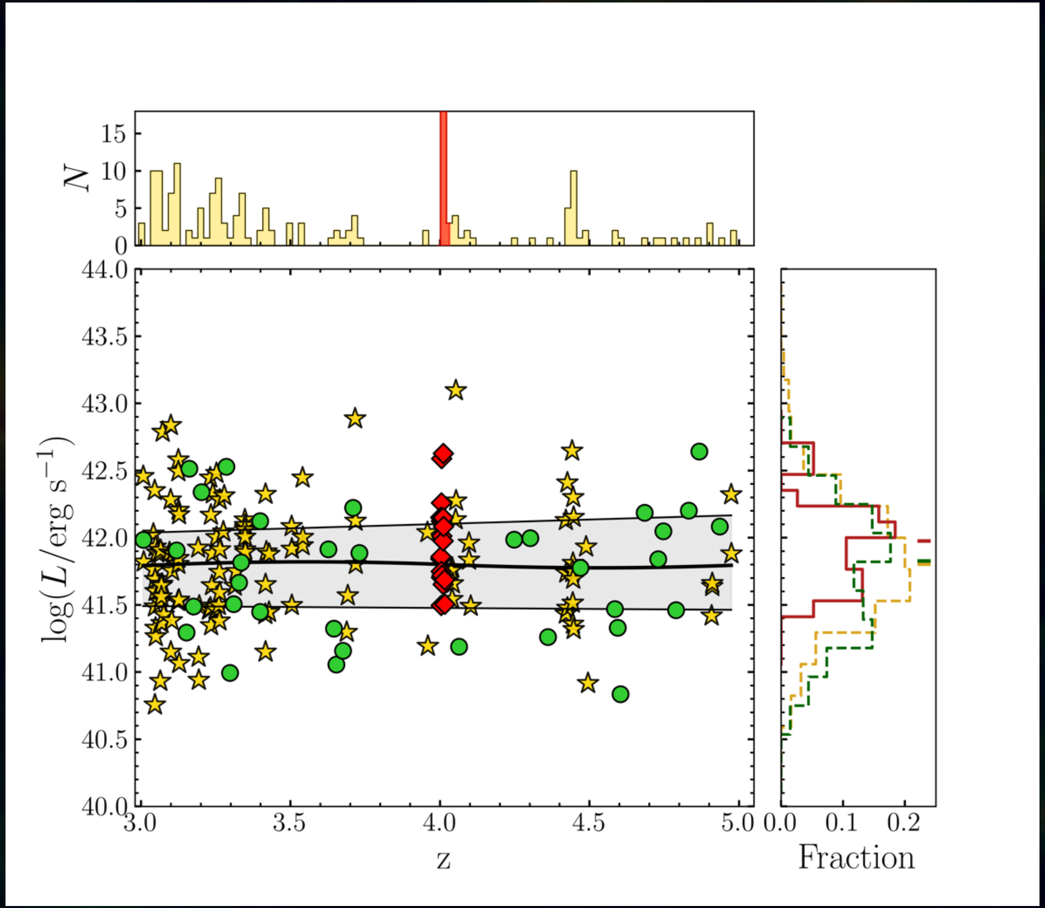
LAEs embedded in the filament z ~ 4

Blue dominated double peaked Lyα lines in $\sim$ 25 % of the LAEs in the group at $z \sim 4$ → synthom of inflow of gas? → enhanced star formation rate? → slight but not evident shift in luminosity respect to a control sample.





D. Tornotti et al., 2024, *ApJL*

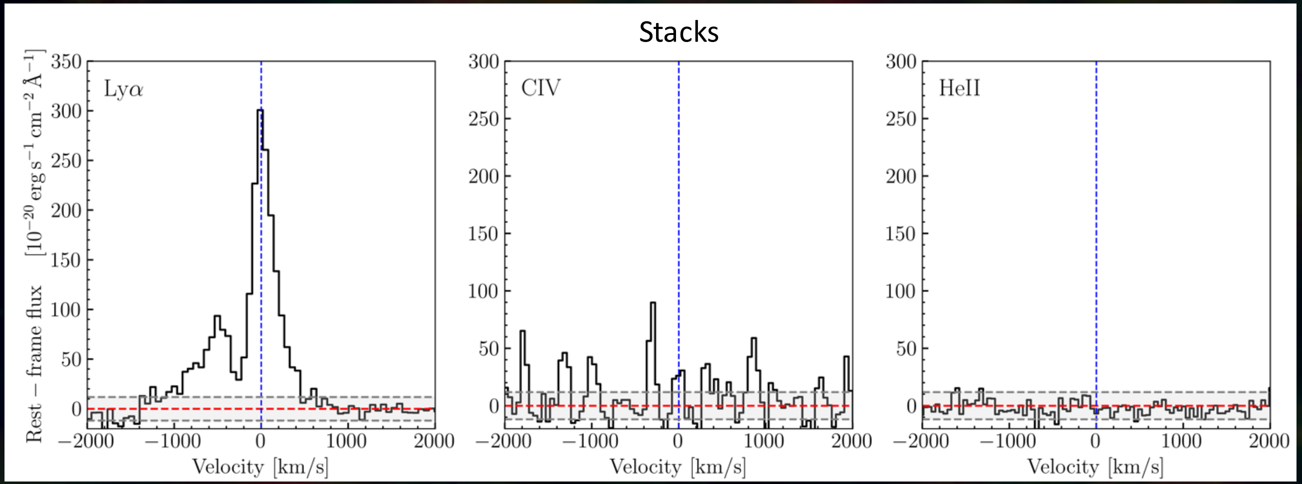
LAEs embedded in the filament z ~ 4

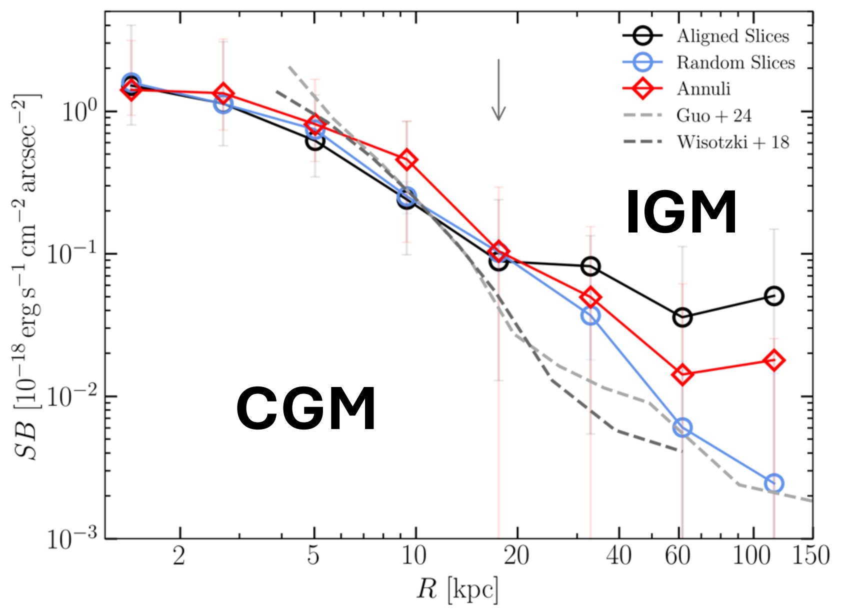
- No bright CIV and HeII emission from single spectra;
- No evident CIV and HeII emission from the stacks of all spectra;

→ upper limit on **AGN activity**

Evidence of inflection point in the SB profiles

→ transition between CGM and IGM





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The future

The future: Wide-Field Spectroscopic Telescope (WST)

Science cases

Across different redshifts ($\sim 2-4.5$) and overdensities ($\sim 5-20$):

I. Tracing the cosmic web: Lyα emission from filaments on ~ 20 cMpc scales (IFS);

II. Galaxy clustering in overdensities: large scale coeval populations on $\gtrsim 150$ cMpc scales (MOS);

III. Lyα absorption tomography: mapping the IGM with background galaxies (MOS);

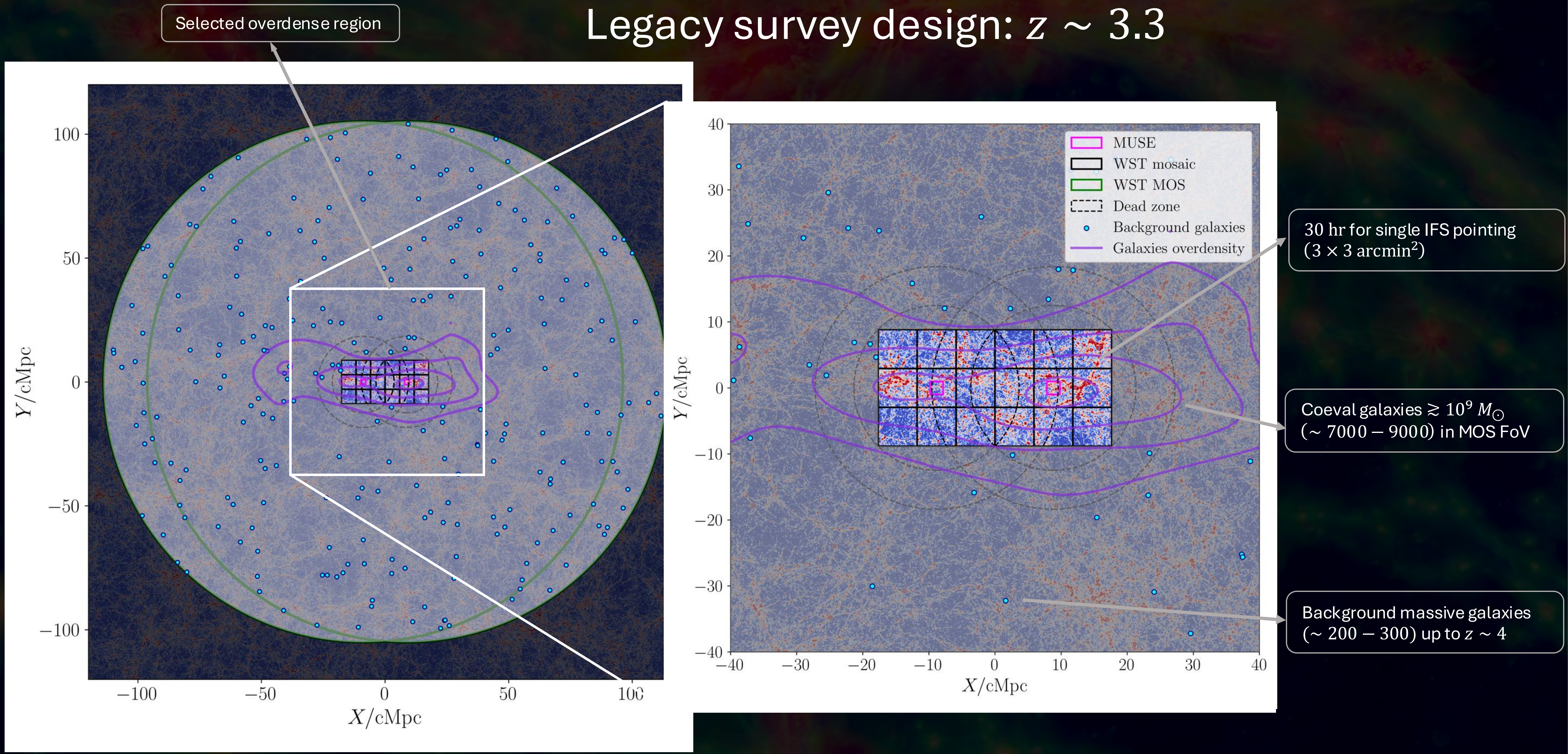
Cosmic Web Legacy survey

Time cost: $\sim$10 nights/yr for 5 years (comparable to long-term investments in other major surveys)

- **2** IFS mosaic pointings: spine of the filaments on ~ 40 cMpc scales ($SB_{\rm lim} \sim 3-4 \times 10^{-20}$ erg s^{-1} cm^{-2} arcsec^{-2});
- $\sim 7000-9000$ MOS fibers for major pointings (background galaxies & coeval galaxies) and $> 1/2$ remain free for additional science cases: galaxy overdensity on ~ 200 cMpc scales and 3D tomography.

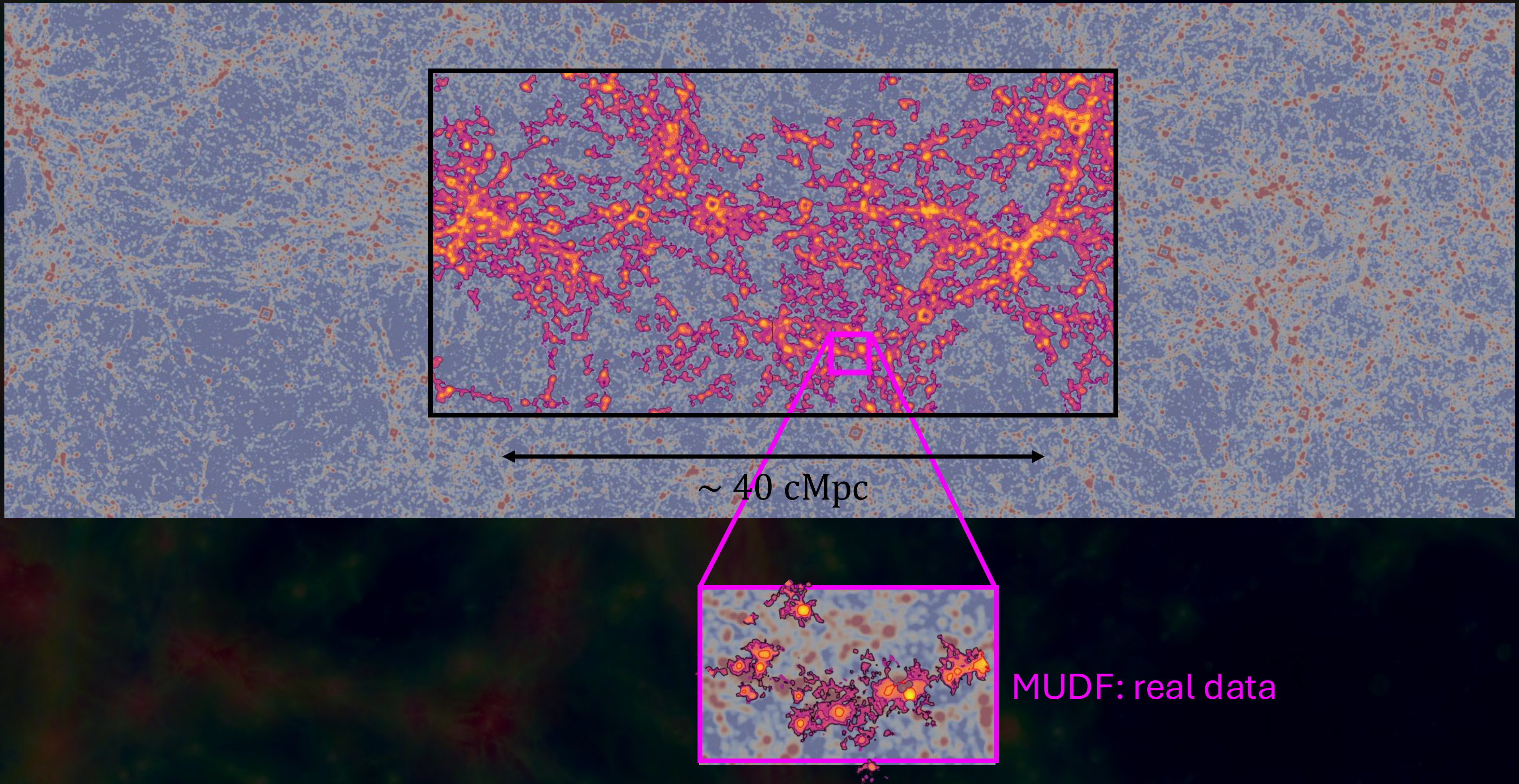
The future: Wide-Field Spectroscopic Telescope (WST)

Legacy survey design: $z \sim 3.3$



The future: Wide-Field Spectroscopic Telescope (WST)

Tracing the cosmic web on unprecedented scales



Summary

- The MUSE Deep Fields have unlocked the ability to study cosmic filaments on scales of the pMpc;

- We can now start to probe different environments (QSOs → LAEs) across different redshifts ($z \approx 3 - 4$);

- This breakthrough opens a completely new window, allowing us to start compiling ***samples*** of filaments and begin constraining their properties statistically;

- WST would provide an unprecedented opportunity to achieve this on scales that are currently beyond our reach.

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Thanks for your attention!

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