Connecting the Dots: Stacking the Cosmic Web in Lyα Emission with MUSE & EAGLE

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& MUSE Collaboration

ETH Zürich

Intergalactic Interconnections
Marseille 2018

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Outline

★Introduction on IGM detection

★Galaxy Sample Selection & Oriented Stacking Procedure

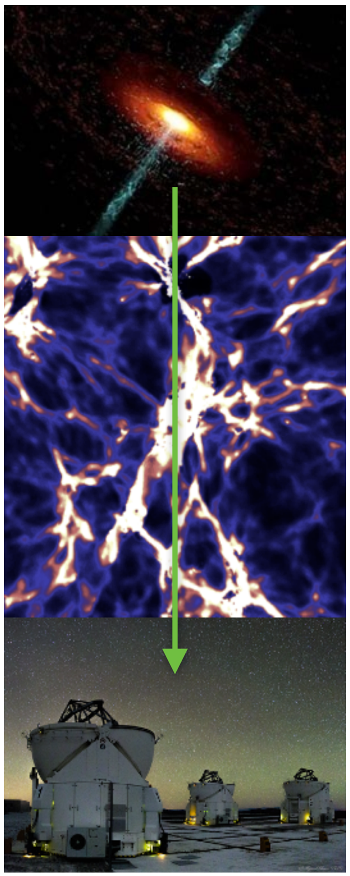
★Results from MUSE stacking analysis

★Constraining IGM-galaxy connectivity and the UVB with simulations

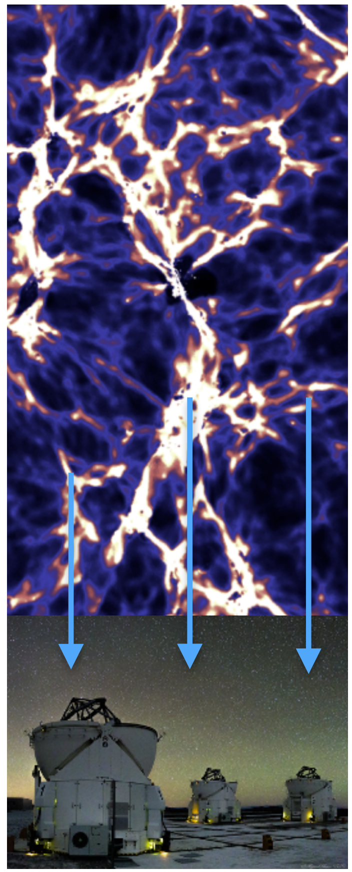
★Summary

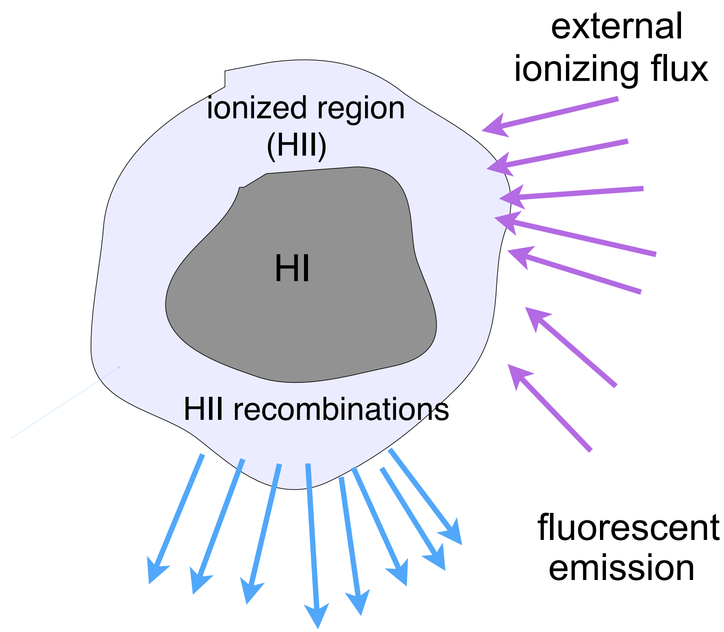
How can we detect the IGM in Lyα?

Absorption



Emission





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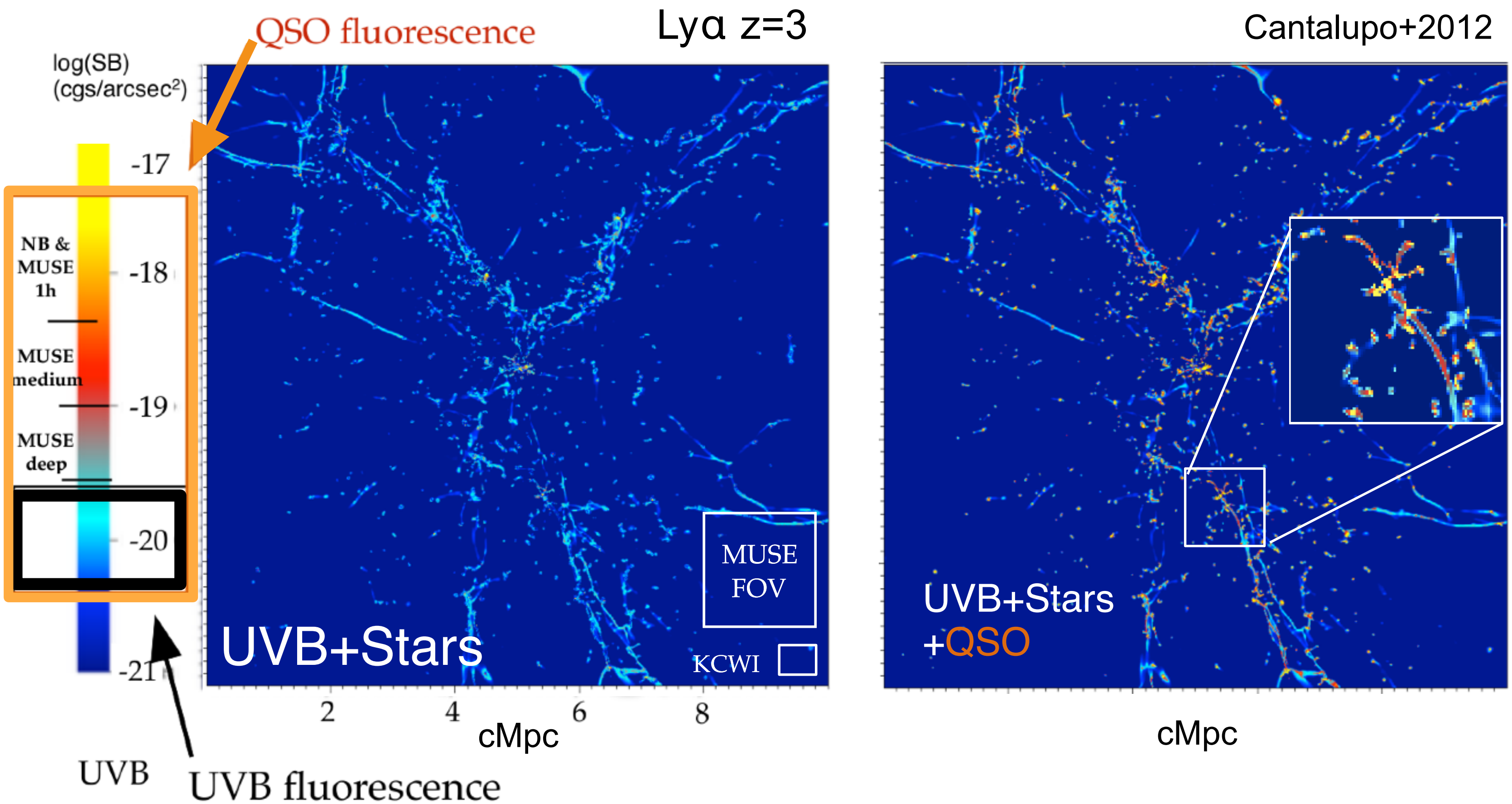
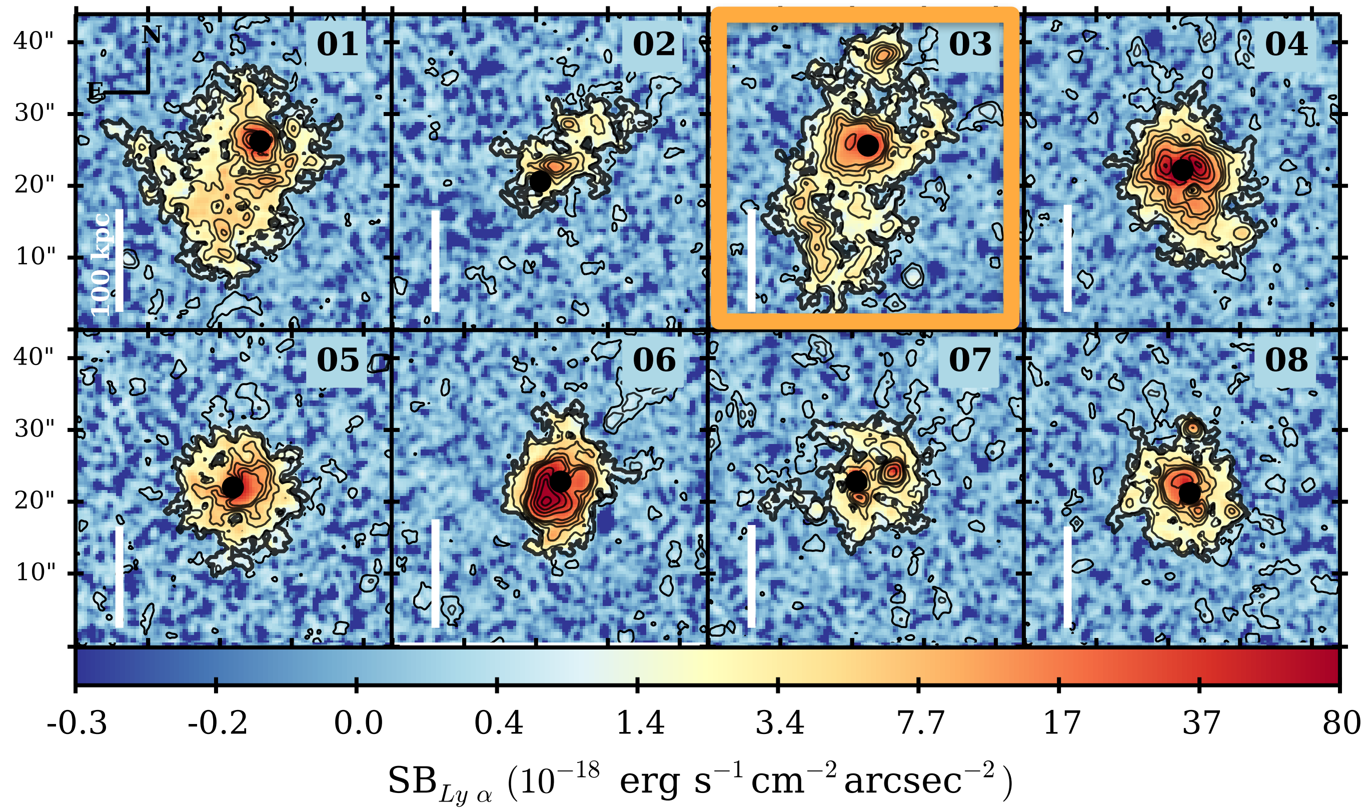
How can we detect the IGM in Lyα emission?



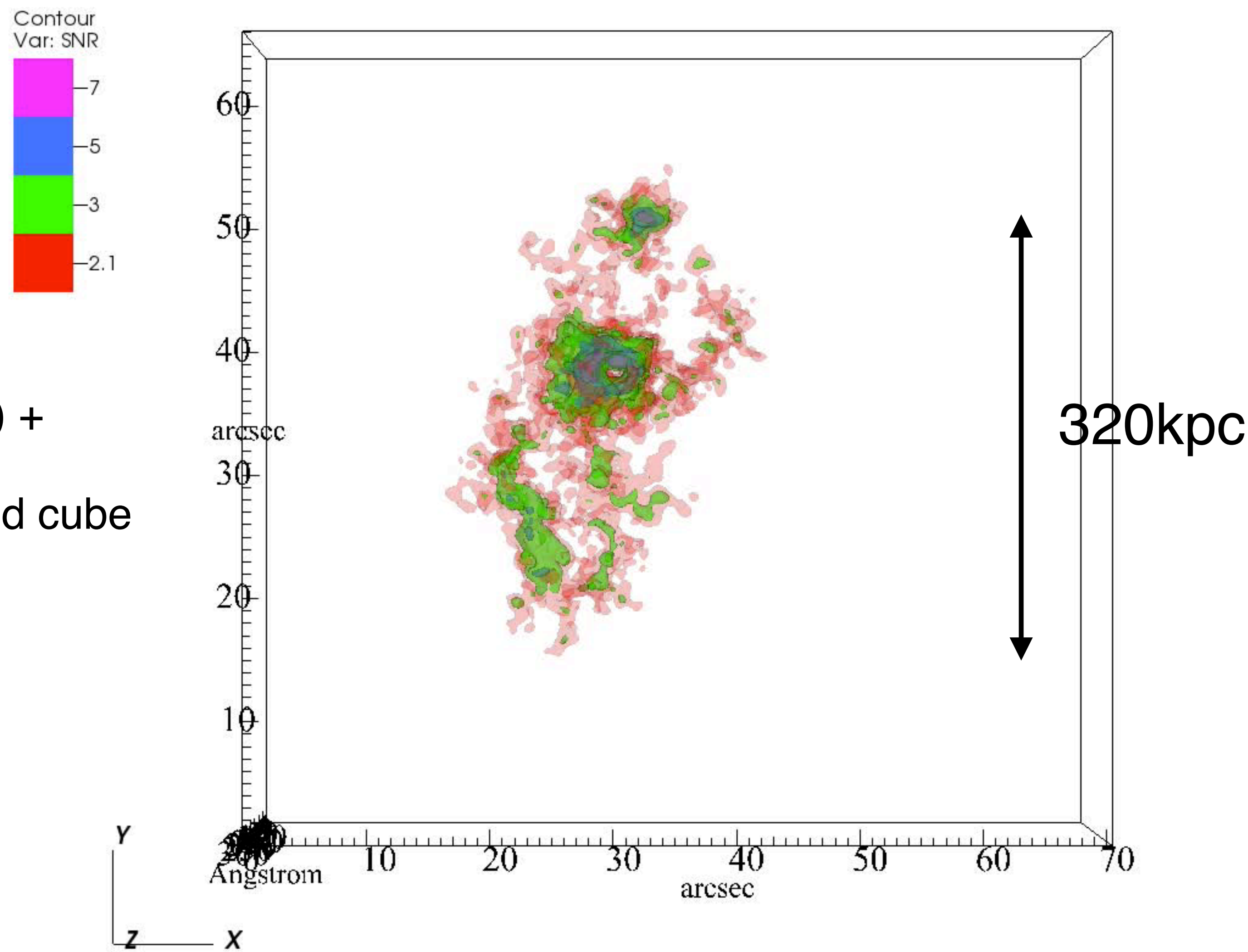
The CGM/IGM around Quasars

Borisova+16



MUSE observations of QSOs at z~3.5: 100% detection rate of giant nebulae!

A 3D view of the Muse Quasar Nebula 3 (MQN03)

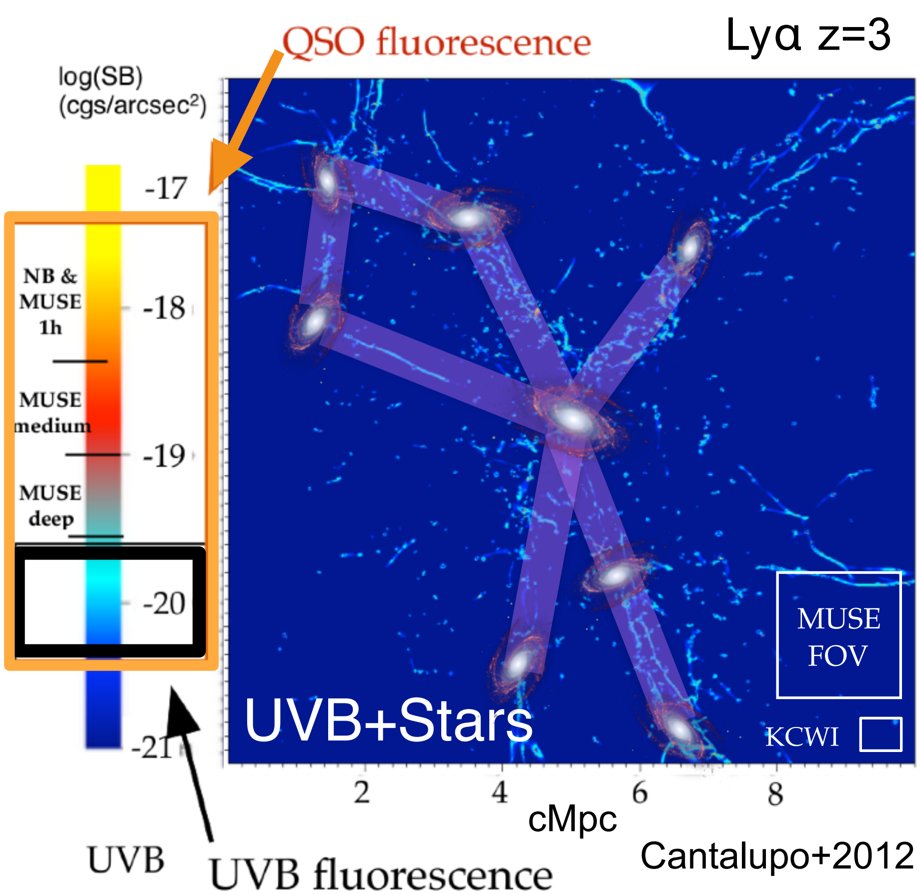


CubExtractor (Cantalupo, in prep.) + VisIt QSO PSF and continuum subtracted cube

$2\sigma \sim 1\times10^{-18}$ cgs/arcsec^2

10 Å ~ 600km/s

IGM Lyα emission away from Quasars?



Cantalupo+2012

- If filaments are LLS their Lyα emission constrains the UV Background (UVB)
- Expected surface brightness (SB) from UVB fluorescence 1.14×10^{-20} erg/s/cm²/arcsec² (z=3.5)
- Current available observations are not deep enough to reach those limits
- Simulations show filaments connecting galaxies
- Oriented stacking along galaxies increase S/N and may show filamentary emission

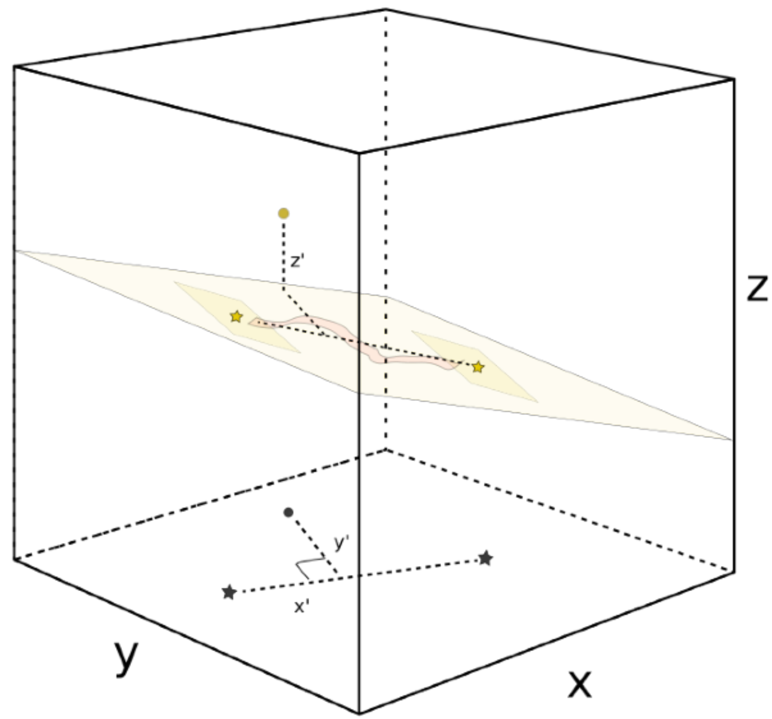
Galaxy Sample Selection & Stacking Procedure

- Lyman alpha emitters (LAEs) selected from the MUSE deep fields HDFS (89, ~26 hrs) + UDF10 (158, ~29 hrs)

- Select LAEs with a "neighbor" within $0.5 < \text{cMpc} < 20$, $\theta > 16''$ and $2.9 < z < 4$ (390)

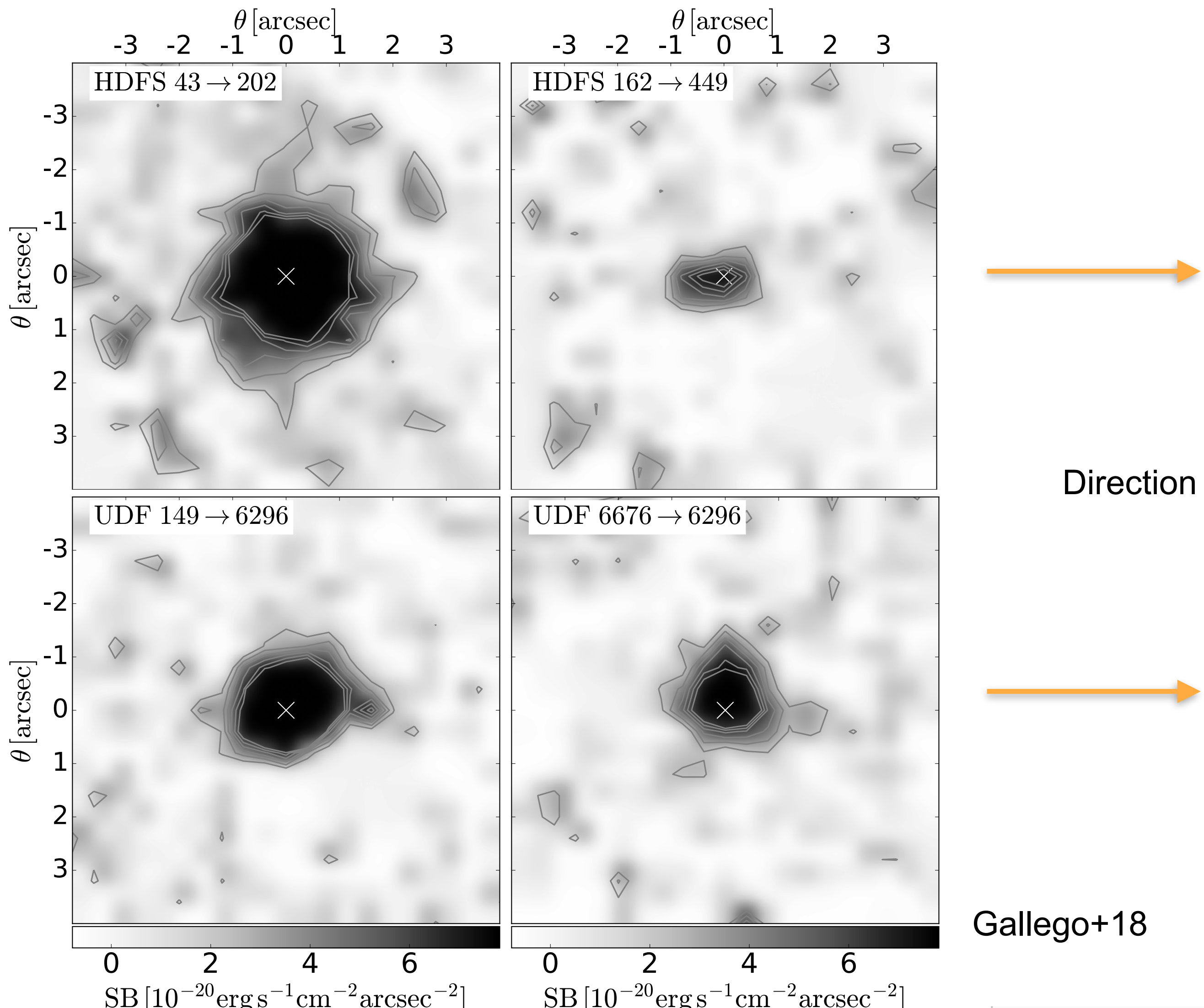
- Obtain subcubes around those LAEs reoriented in the direction of the close neighbor

MUSE



Example of Neighbor-Oriented Lyα Narrowband Images

6.25 Å



Direction of Neighbors

Gallego+18

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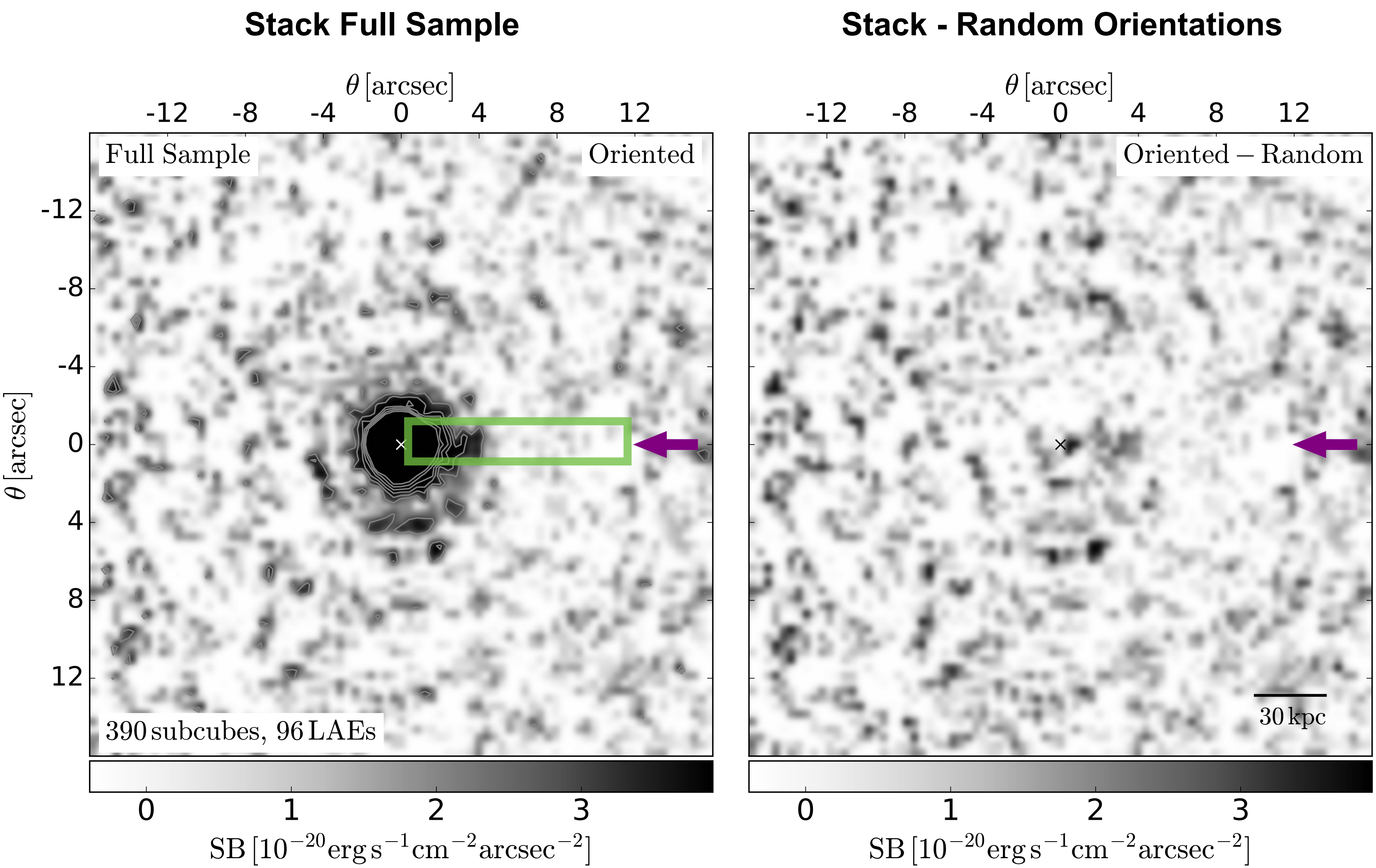
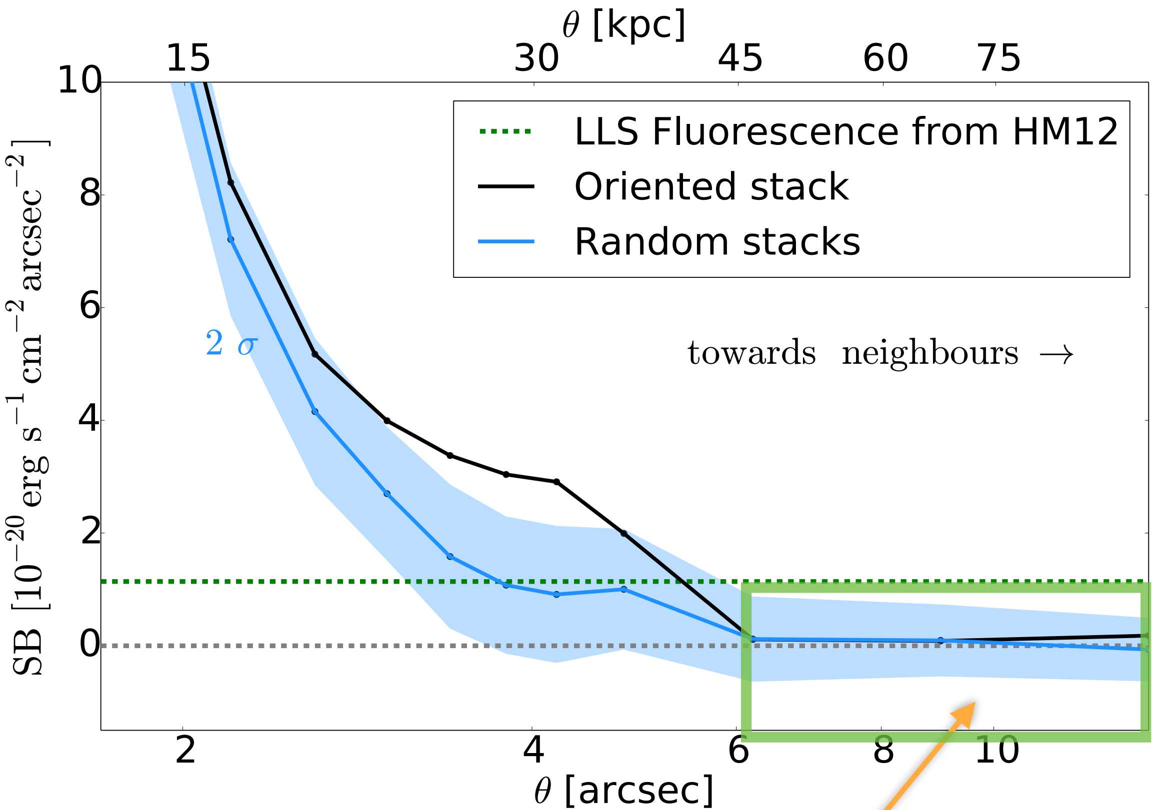
Oriented Stacking



Gallego+18

SB profile along direction of neighbors



SB Haardt & Madau 2012:
1.14×10^{-20} erg/s/cm^2/arcsec^2

~18x deeper than the individual cubes!

SB 2σ between 6” and 12”:
0.44×10^{-20} erg/s/cm^2/arcsec^2

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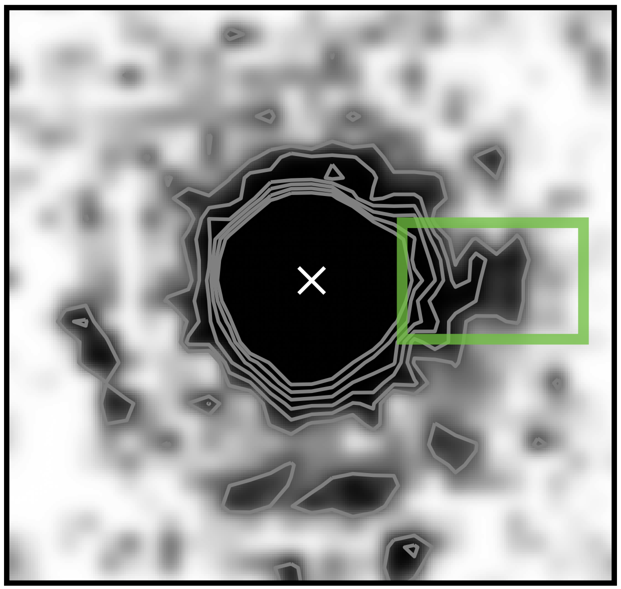
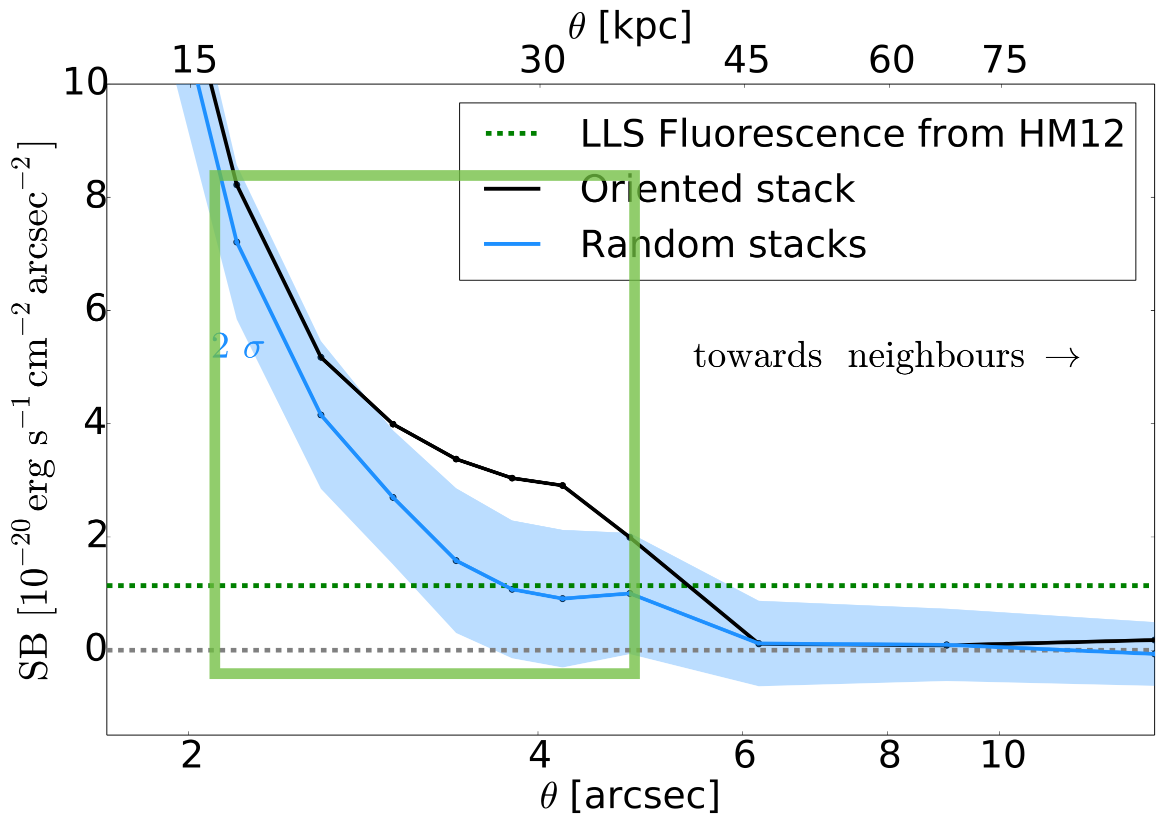
Excess of Oriented Emission at CGM scales





~3.5 sigma excess over random orientations
20 kpc < θ < 30 kpc.

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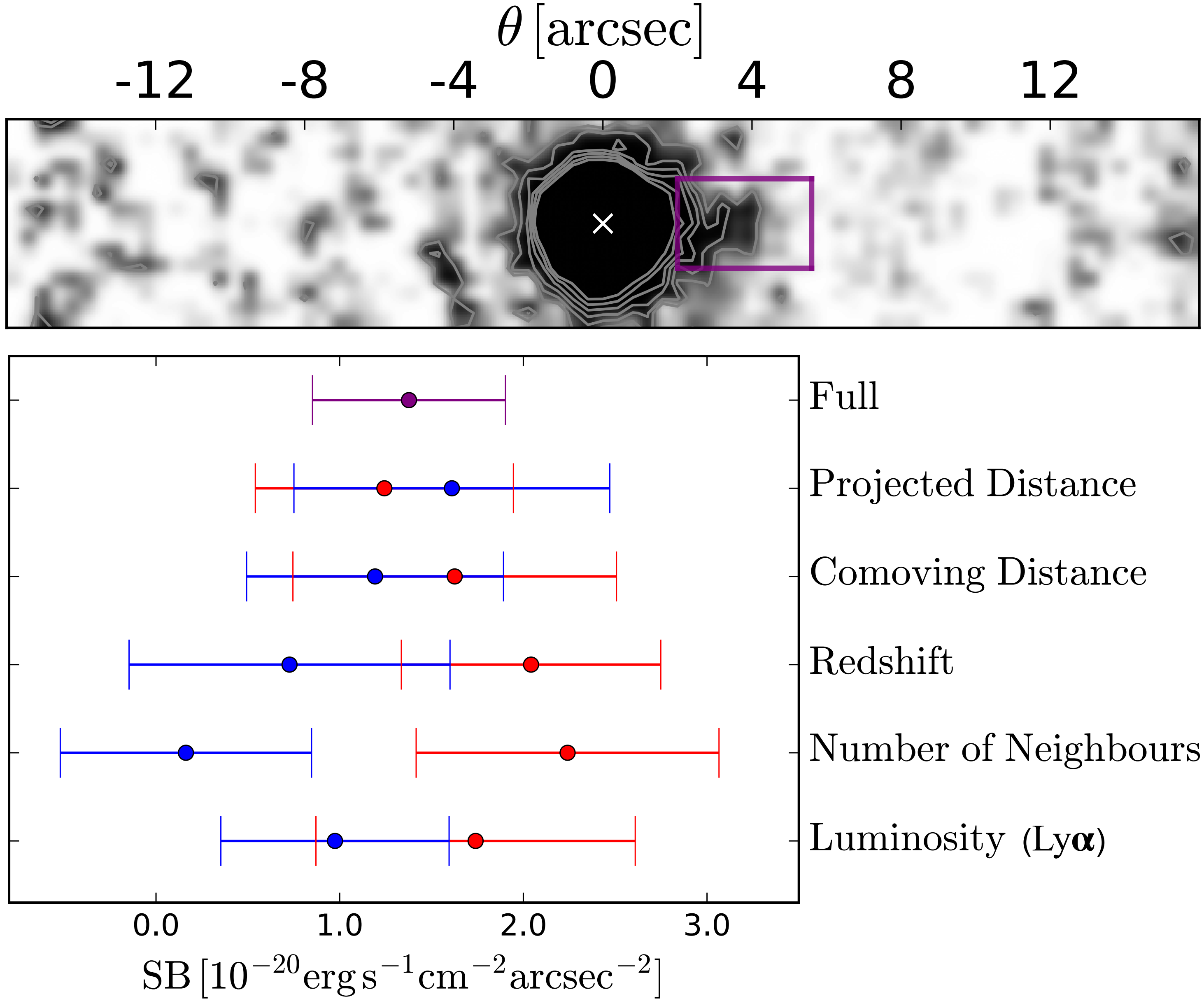
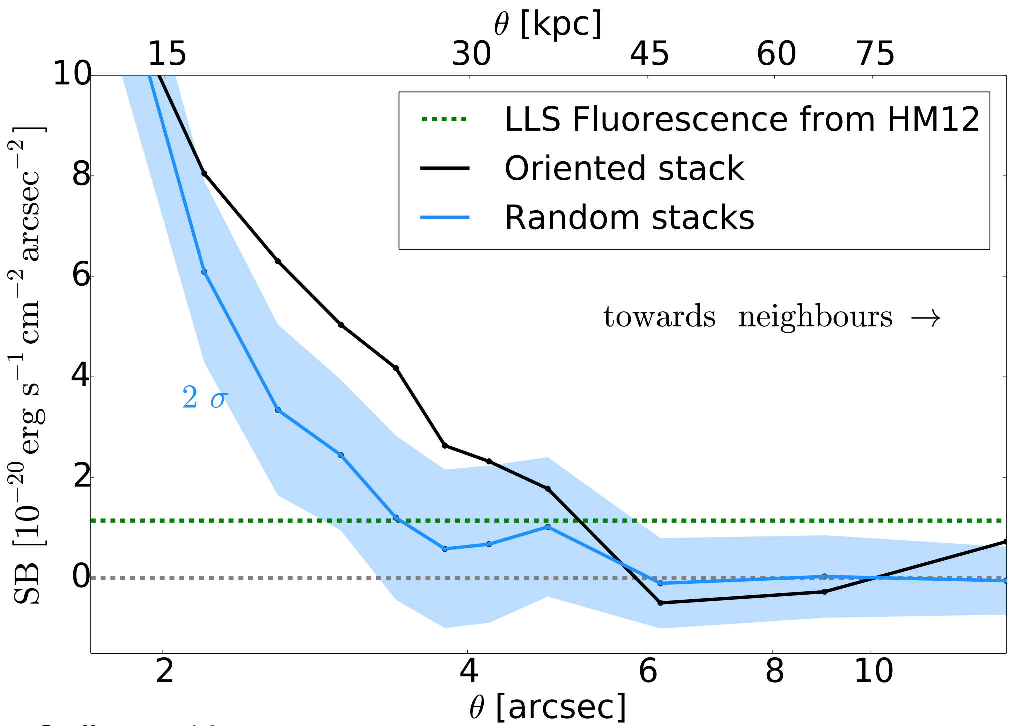
Excess of Oriented correlates with Number of Neighbors



Gallego+18

What is the Origin for the oriented CGM emission?

Sample with more neighbors



Gallego+18

Satellite galaxies

CGM assymetries*

- Galaxy fluorescence

- Lyα scattering from the central galaxies

*Imply statistically higher densities toward neighbors (0.5 < d < 20 cMpc)!

→ CGM Filaments?

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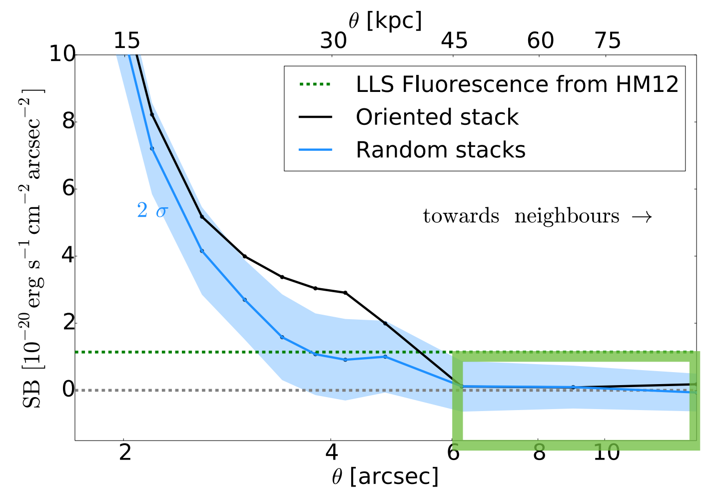
What does the lack of emission imply at IGM scales?

i) UVB is a factor of 3 or more below expectations at z~3.5 (very unlikely), OR

ii) IGM filaments are not LLS, OR

iii) Not all galaxy pairs have filaments ($f_{conn} < 1$)

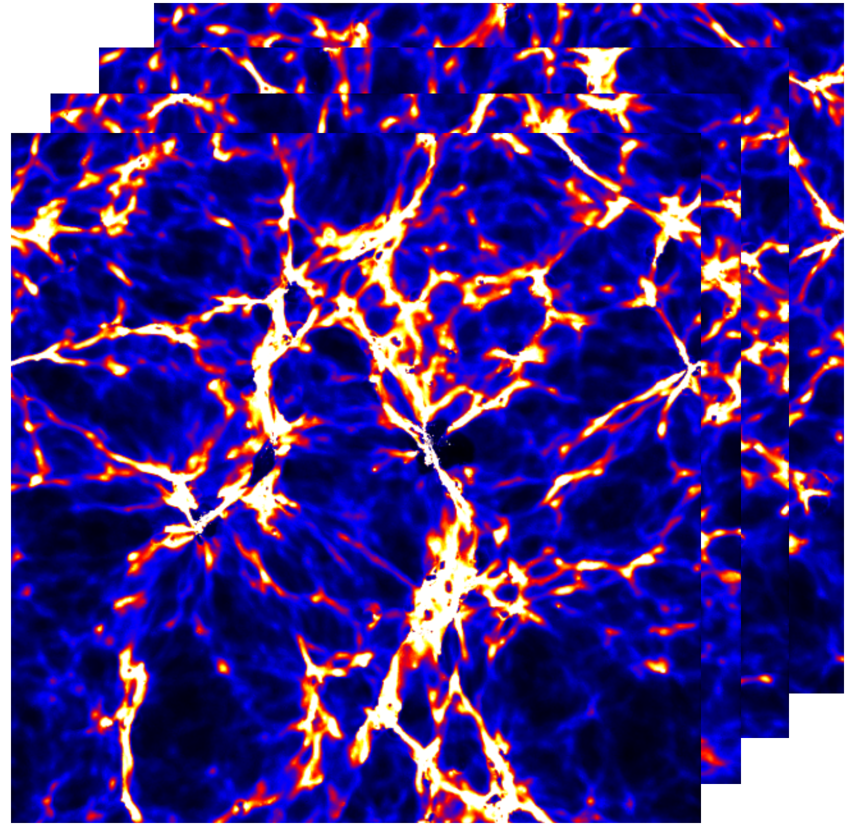


What are the galaxy properties that increase our chances of detecting the Cosmic Web?

Can we contrain both the number of galaxies connected by LLS filaments f_{conn} and the brightness of the UVB?

Simulations: EAGLE

- ✦ Ref-L0025N0752
- ✦ 25 $cMpc^3$
- ✦ 3 snapshots from $3 < z < 4$
- ✦ from 0.16 to 0.19 arcsec/pixel (similar to MUSE!)
- ✦ FoV from ~114 to ~213 $arcmin^2$



SB mock cube

Gallego+ in prep

Steps:

- Produce mock cubes from simulations
- Apply same selection criteria of Gallego+18 on the EAGLE galaxy catalog

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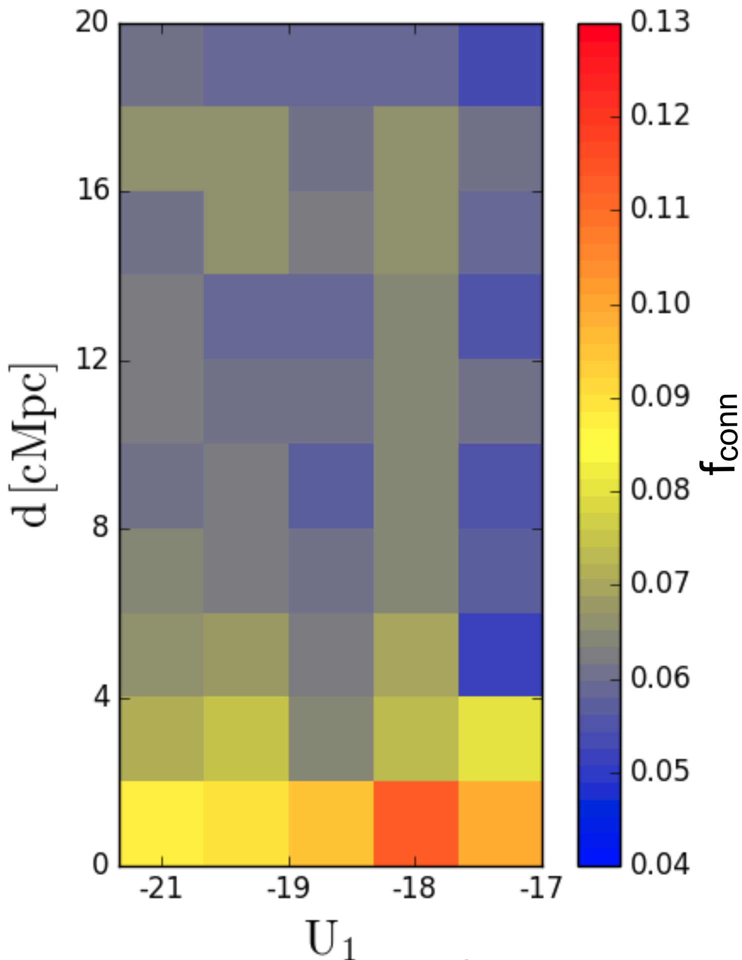
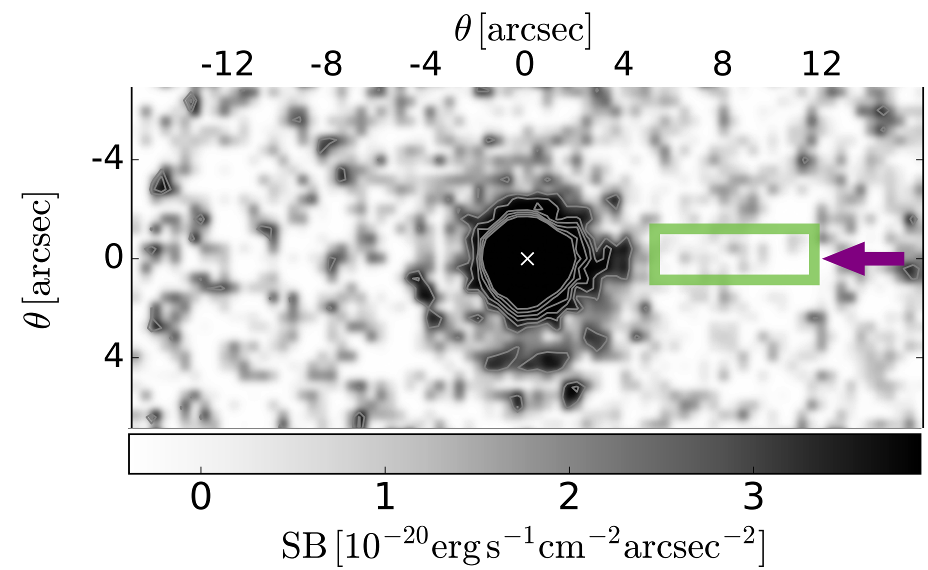
Constraints on f_{conn}

z=3.5



Gallego+ in prep

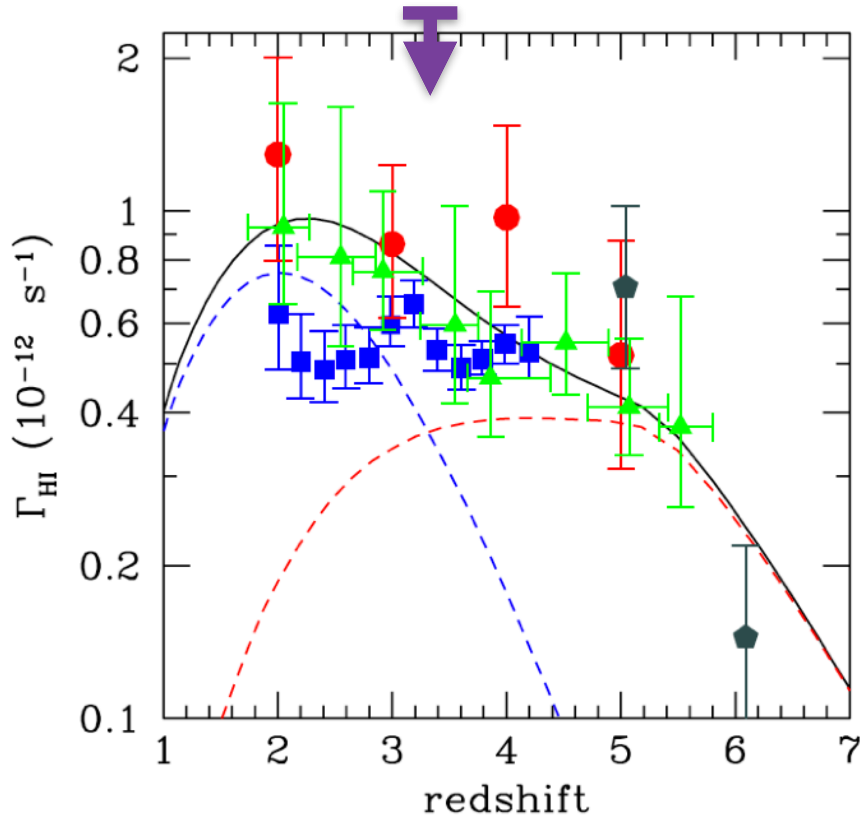
f_{conn}: the fraction of galaxies connected by LLS at a given distance and luminosity in our region of interest, 1" height and from 6" to 12" length



Constraints on the UVB

★Total f_{conn} from our full sample ~0.09

★SB upper limit (2σ SB limit / f_{conn}) = 4.89 x 10^{-20} erg/s/cm^2/arcsec^2



Current upper limit for Gallego et al.18 + EAGLE

Γ_{HI} < 2.35 x 10^{-12} s^{-1}

Next step: Improve sample selection

Haardt & Madau 2012

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Summary

★ We performed an oriented stacking of LAEs in the direction of neighbouring galaxies with MUSE at z~3.5 (Gallego+18).

★ Excess of emission is found on CGM scales (<30kpc), it seems stronger for LAEs with more neighbours and independent of other galaxy properties (luminosity, redshift, distance to neighbours).

→ Satellites, galaxy fluorescence or Lyα scattering?

★ No emission is found at IGM scales (>30 kpc) with a 2σ SB limit of 0.44×10^{-20} erg/s/cm^2/arcsec^2.

★ Using Gallego+18 results in combination with EAGLE constraints, we obtain the covering fraction of LLS $f_{conn} \sim 9$ % and an upper limit of the photoionisation rate at z~3.5 of $\Gamma_{HI} < 2.35 \times 10^{-12}$ s^{-1}.

★ Next step: improve our sample selection with EAGLE to improve UVB constraints and possible to detect IGM filaments