Observational Connections between Galaxy and Structure Formation at Cosmic Noon

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Collaborators:

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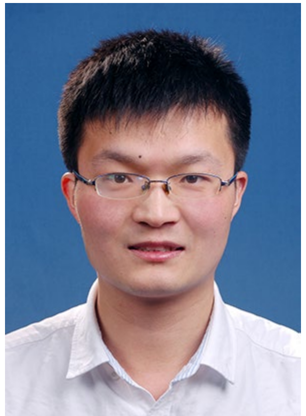
- Liu S. et al. 2023, MNRAS, 523, 2422
- Shi D.D. et al. 2023 (2303.09726)
- Wen R. et al. 2022, ApJ, 933, 50
- Zhang Y. et al. 2022, MNRAS, 512, 4893
- Ren J. et al. 2022, MNRAS, 510, 3071
- Shi D.D. et al. 2021, ApJ, 915, 32
- Zheng X.Z. et al. 2021, MNRAS, 500, 4354



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刘爽/Liu S.

文润/Wen R.

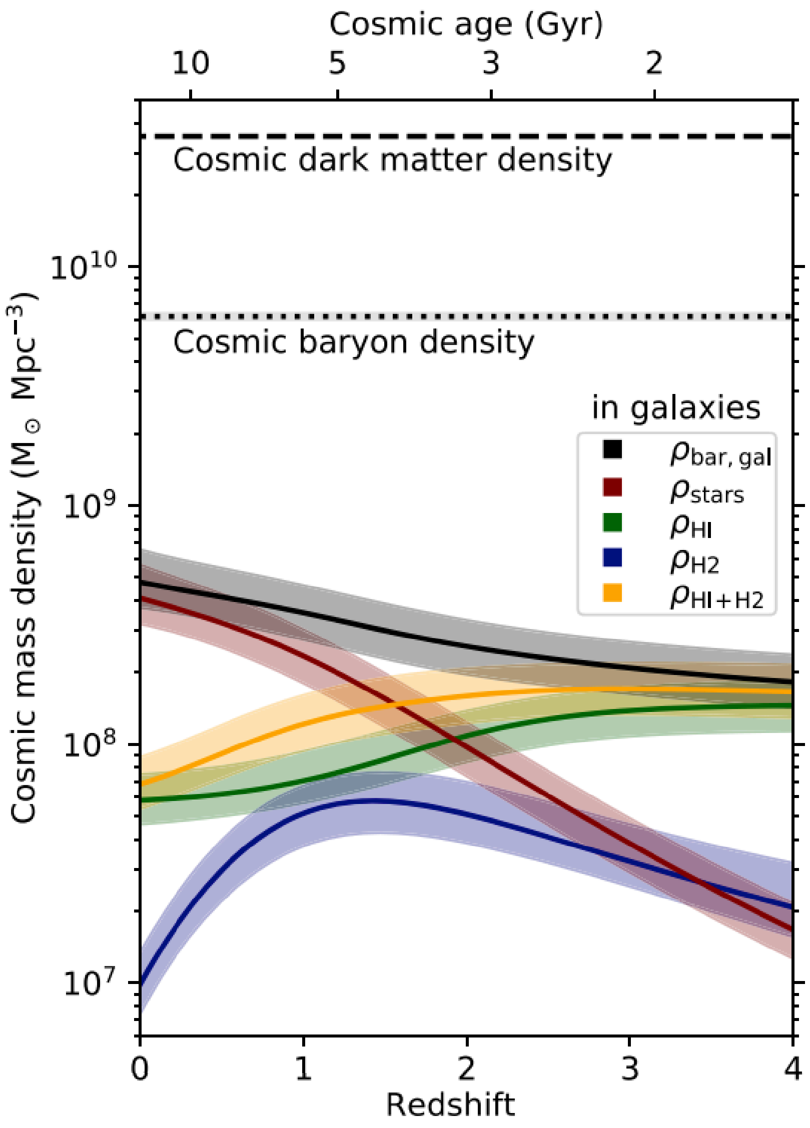
任建/Ren J. @ NAOC

张钰恒/Zhang Y. @IAC

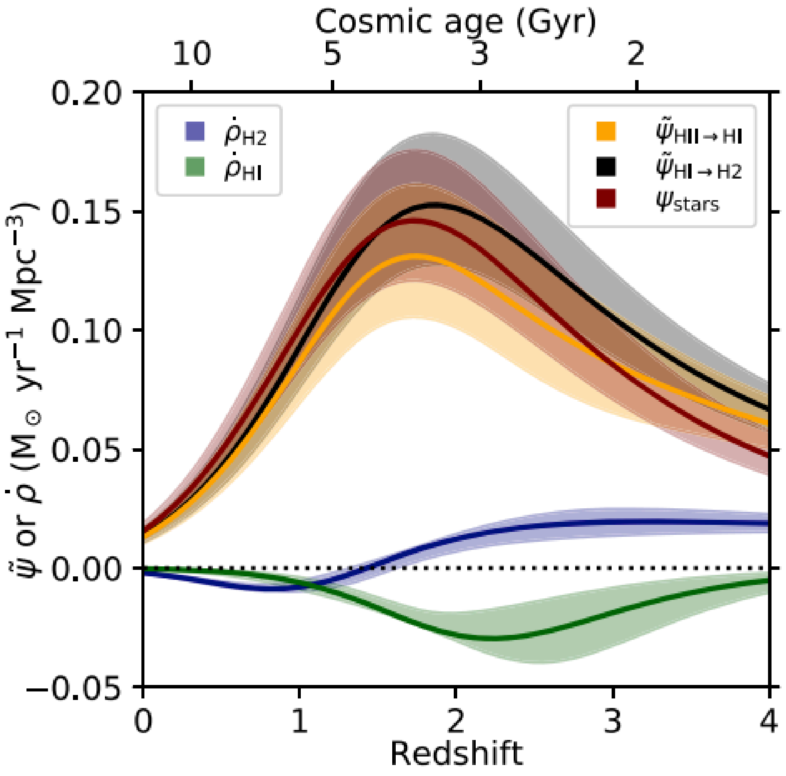
- **How did galaxies form and evolve in massive protoclusters at cosmic noon (z=2-3) ?**
- **How did the cosmic sheet effect on star formation in member galaxies?**

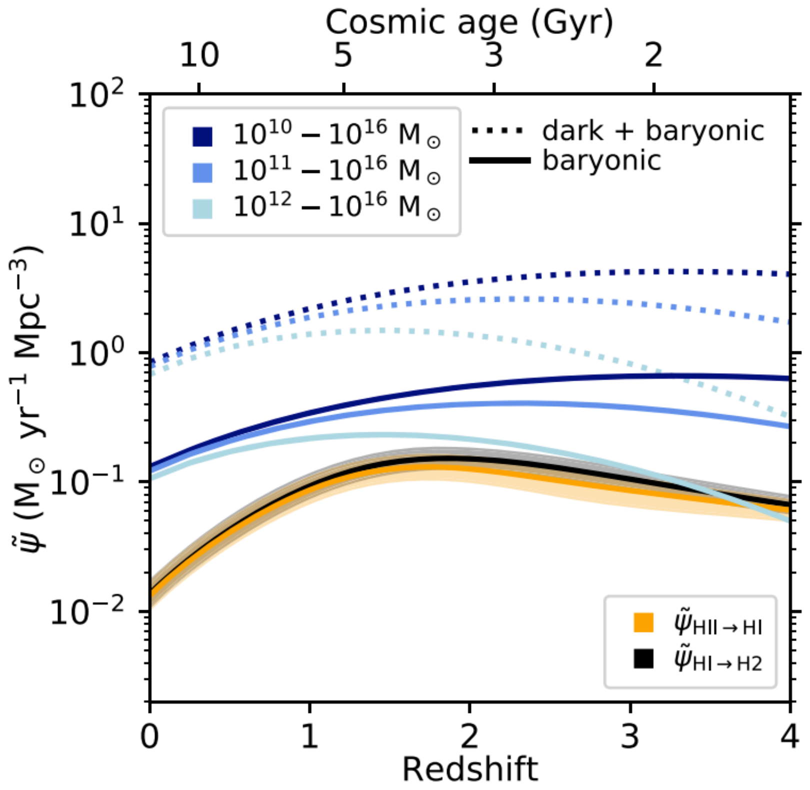
The Evolution of Baryon Matters in Galaxies Across Cosmic Age

Galaxy Halos contain only ~8% of total baryon matter.



Walter+2020





Cen & Ostrike 1999 -- Where are the baryons?

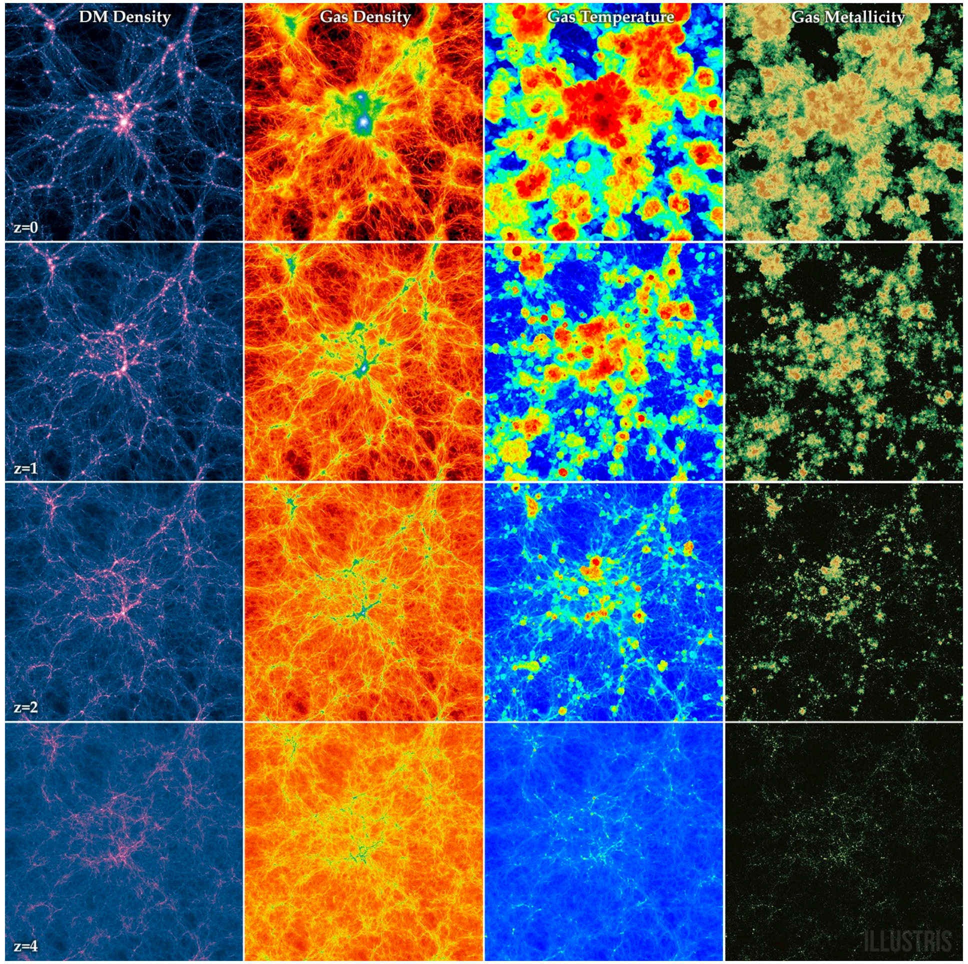
What are the dominant quantities for the growth of galaxies?

What determine a seed galaxy at cosmic dawn to become a giant or a dwarf today?

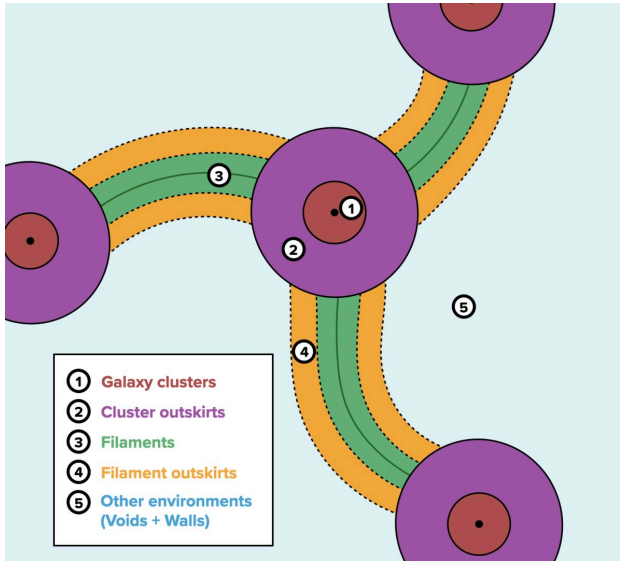
- Galaxy mass appears as a dominant quantity for forming the scaling relations of galaxies (M_{halo}-M*, SFR-M*, Σ_{gas}-Σ_{SFR}, M_{BH}-M_{bulge}, $Z/Z_{\odot}$-M*, Re-M*).
- Galaxy growth is driven by star formation and galaxy mergers . What control these processes regulating the growth?
- **The cosmic environment** refers to the available matter reservoirs and surrounding tidal field, and determines the matter flowing: **nourishing** vs **starving** .
  - ✓Dwarf galaxies may grow to massive ones in a nourishing site, but cease star formation once entering a starving place (e.g. hot haloes).
  - ✓Massive galaxies can still grow through star formation fueled by cold gas from the cosmic web, or galaxy mergers in dense environments.
- **What key quantities/parameters describe the degree of nourishing (or starving)?**

Cosmic Environments and Large-Scale Structures

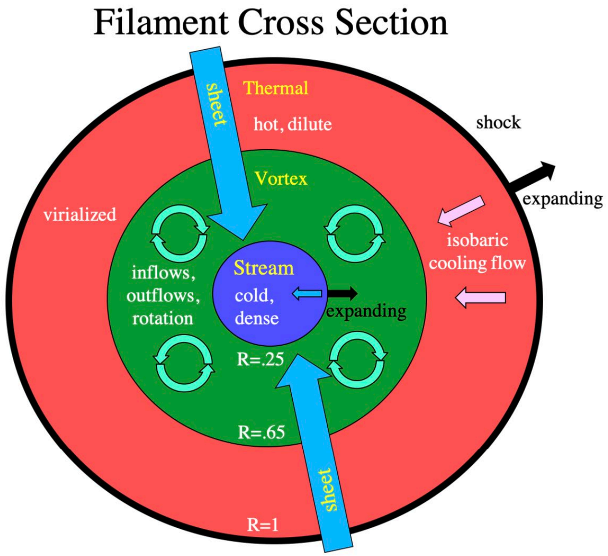
The ILLUSTRIS simulations



Galárraga-Espinosa+2023



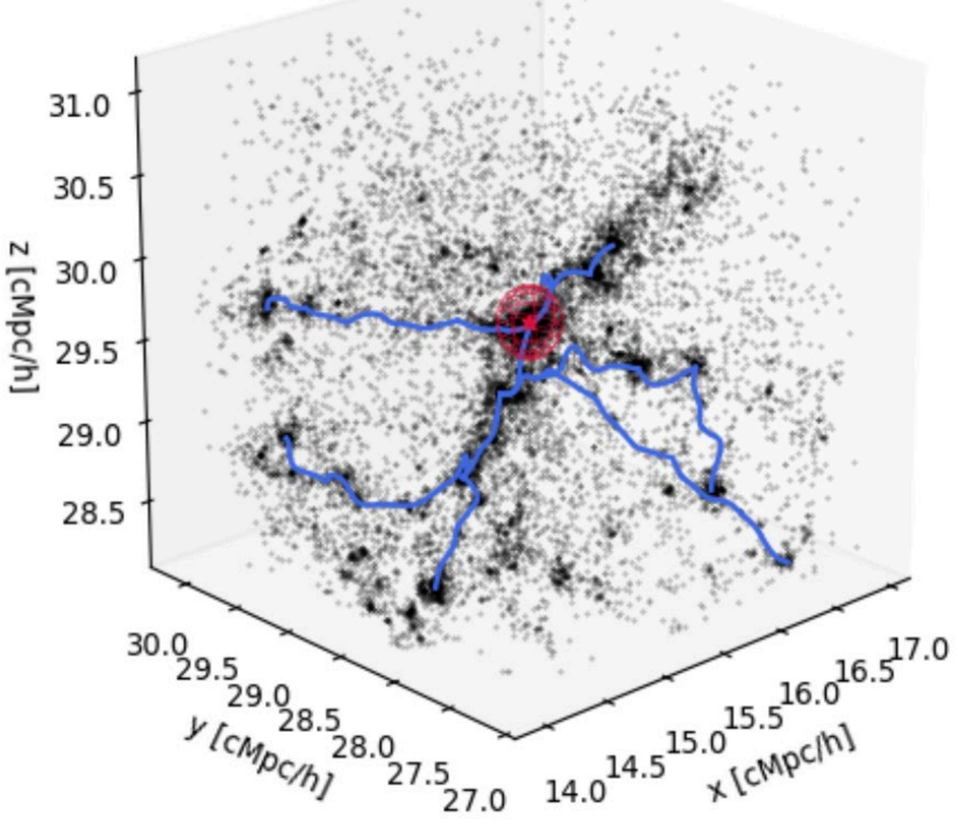
Lu Y.S.+2023 (2306.03966)



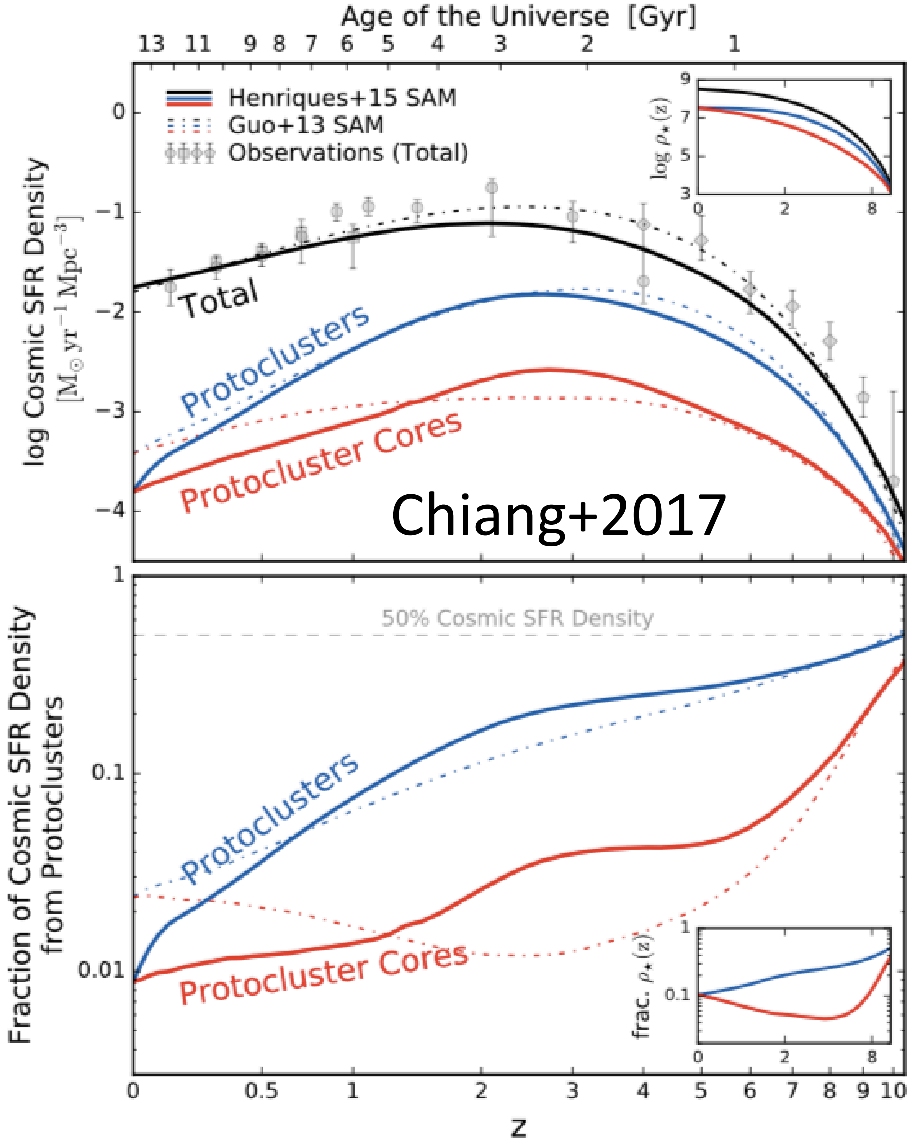
- **Large-Scale Structures** (~3-30 Mpc; filaments, clusters, sheets): potential well to keep and cool down gas
- **Medium-Scales** (~0.3-3 Mpc; subclusters, groups): take Gyrs to flow into galactic halos
- **Galactic Halos** (<~0.3 Mpc): accretion shocks; cold streams penetrate into cold halos at high z; heated up by accretion of satellites or mergers?

Cosmic Environment Regulates Galaxy Growth

The available matter reservoirs and surrounding tides govern the growth.

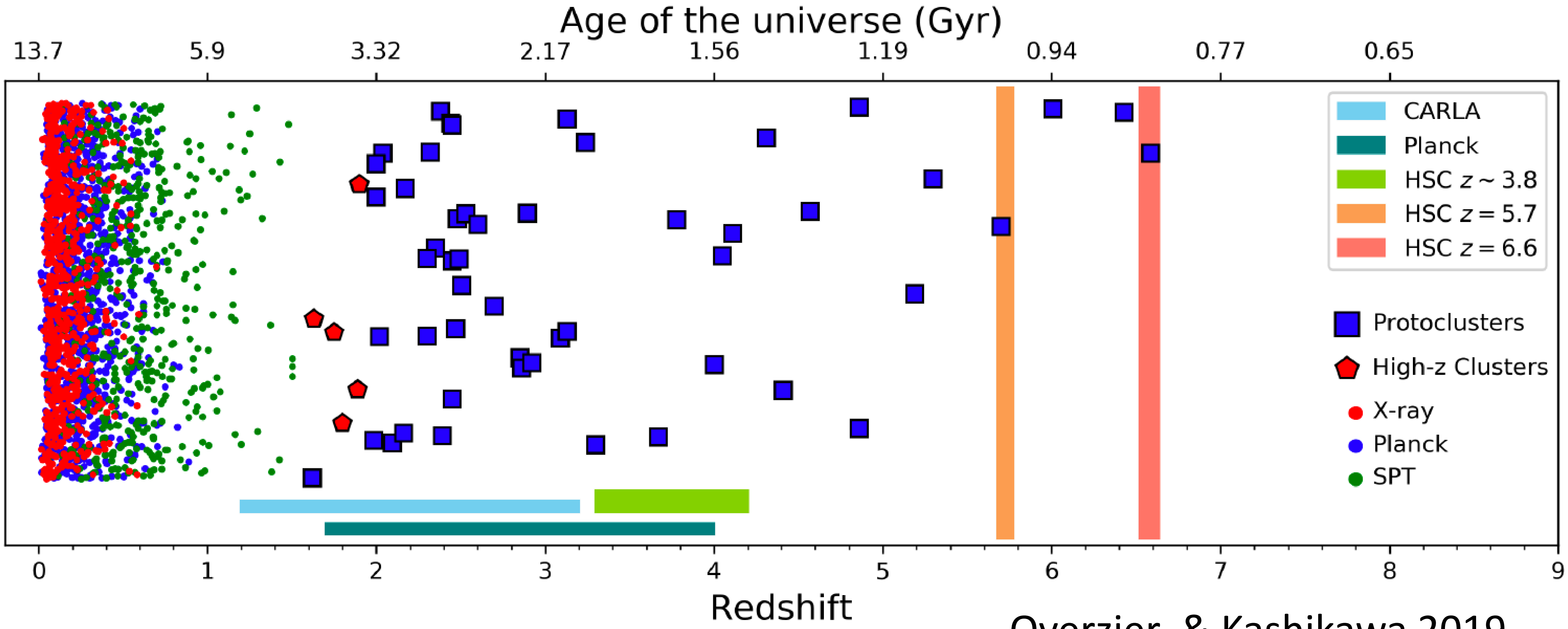


Galárraga-Espinosa+2023, A&A, 671, A160



How Did Galaxy clusters Form?

星系团早期如何形成？ 结构的形成如何决定成员星系的形成演化？



Overzier & Kashikawa 2019

SSA22：A extended and massive Structure

Umehata et al. 2017

2’ x 3’ = 0.9 x 1.3 Mpc @3.1

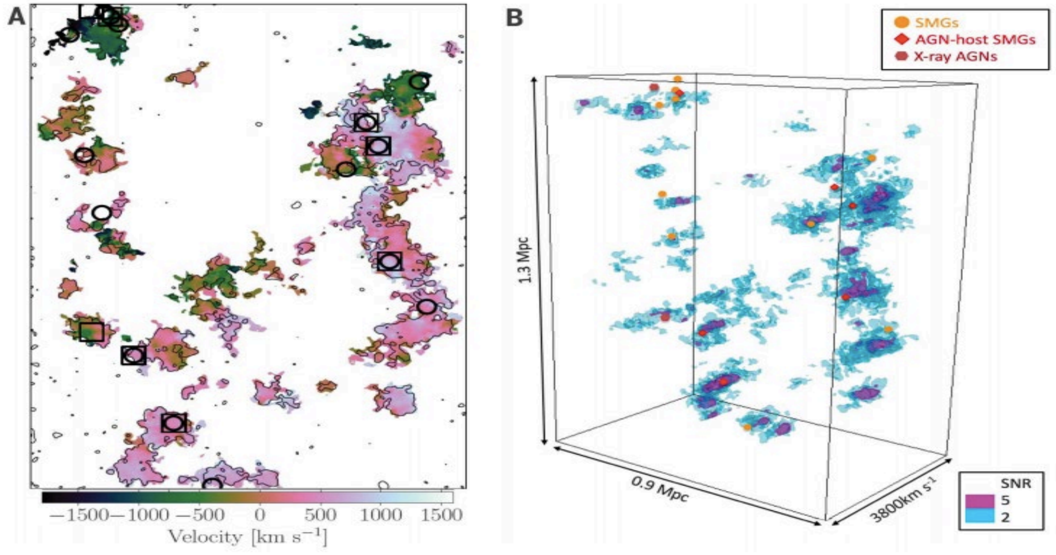
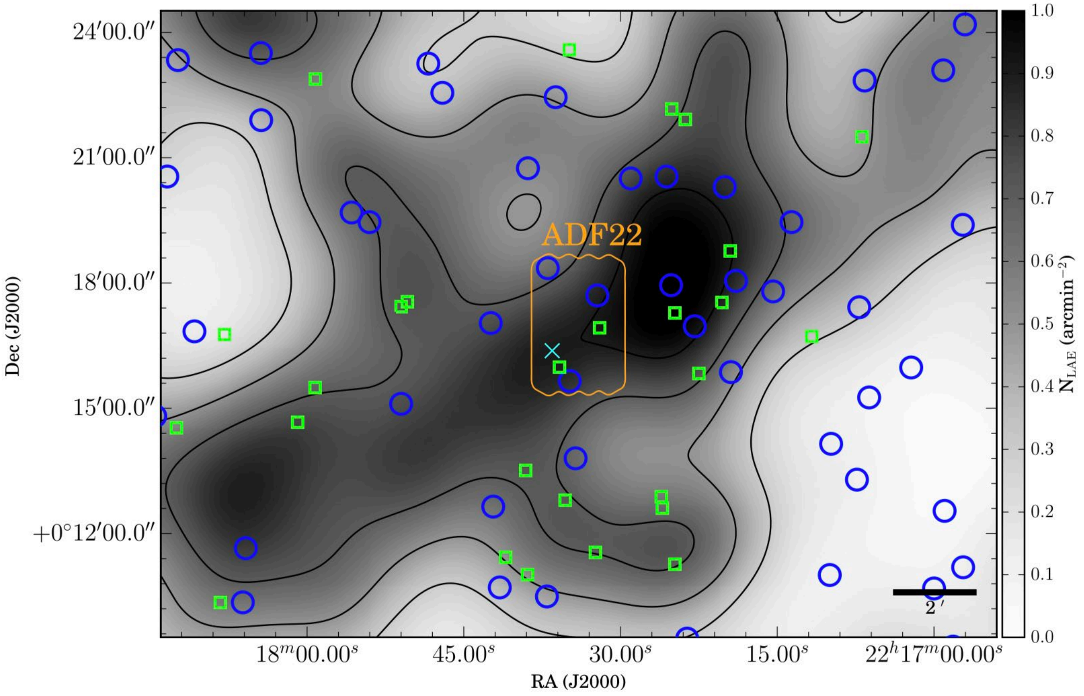


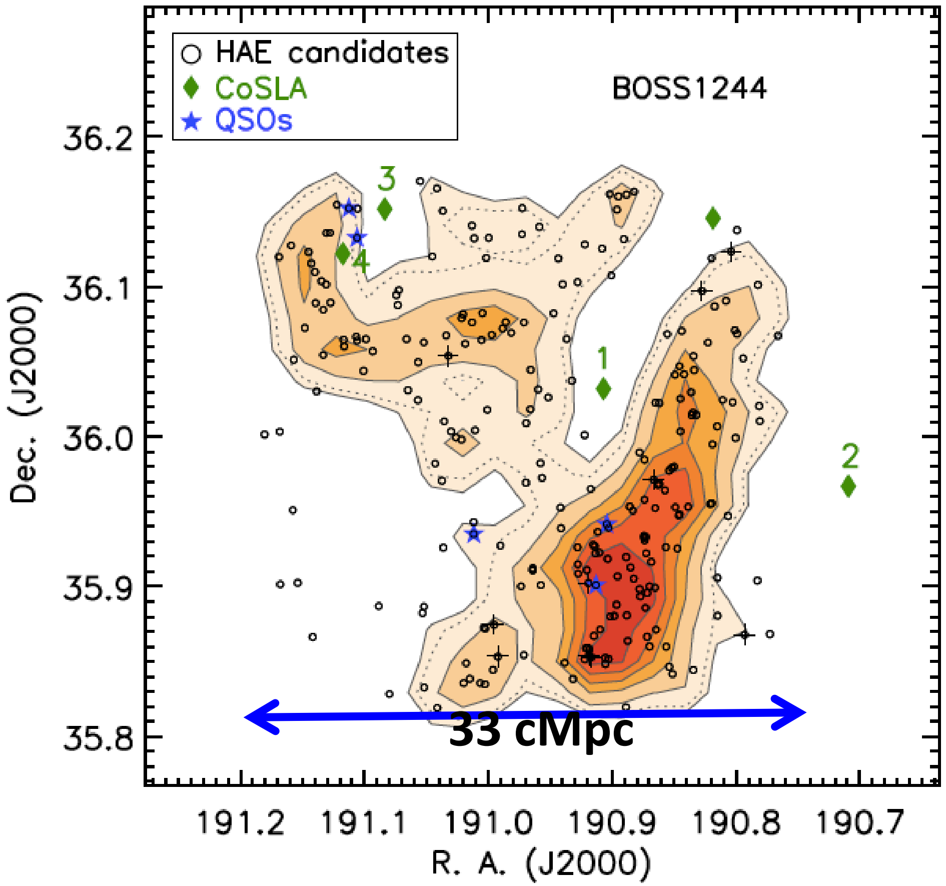
Fig. 3. Three-dimensional pictures of Lyα filaments. (**A**) Velocity map of the Lyα emission obtained from its flux-weighted centroid in the MUSE data. Image scale and plotting symbols are the same as those in Fig. 2. Coherent velocity trends can be seen along the filament structures. (**B**) The 3D distribution of *Lyα filaments shown with blue [signal-to-noise ratio (SNR) > 2] and magenta (SNR > 5) voxels. The locations* of SMGs (without detectable x-ray AGNs, orange circles), AGN-hosting SMGs (red diamonds), and

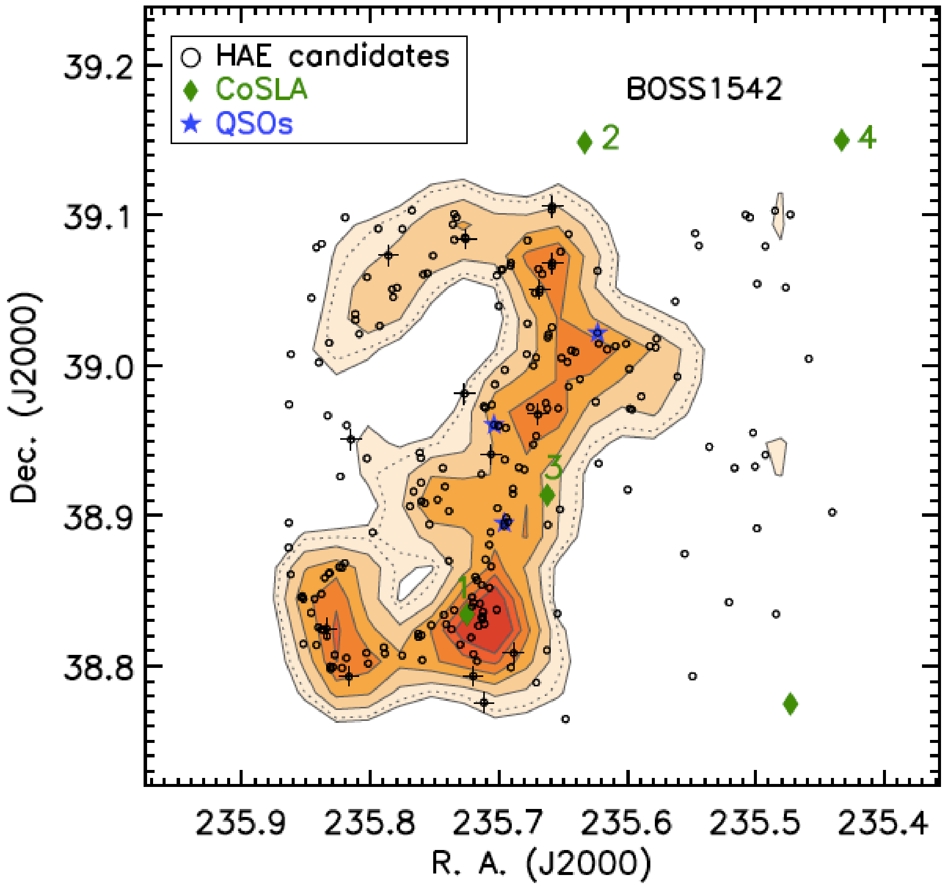


Umehata+2019

Gas flowing in filaments and fueling exteme starbursts

Discovery of Two Massive Protoclusters at z=2.24

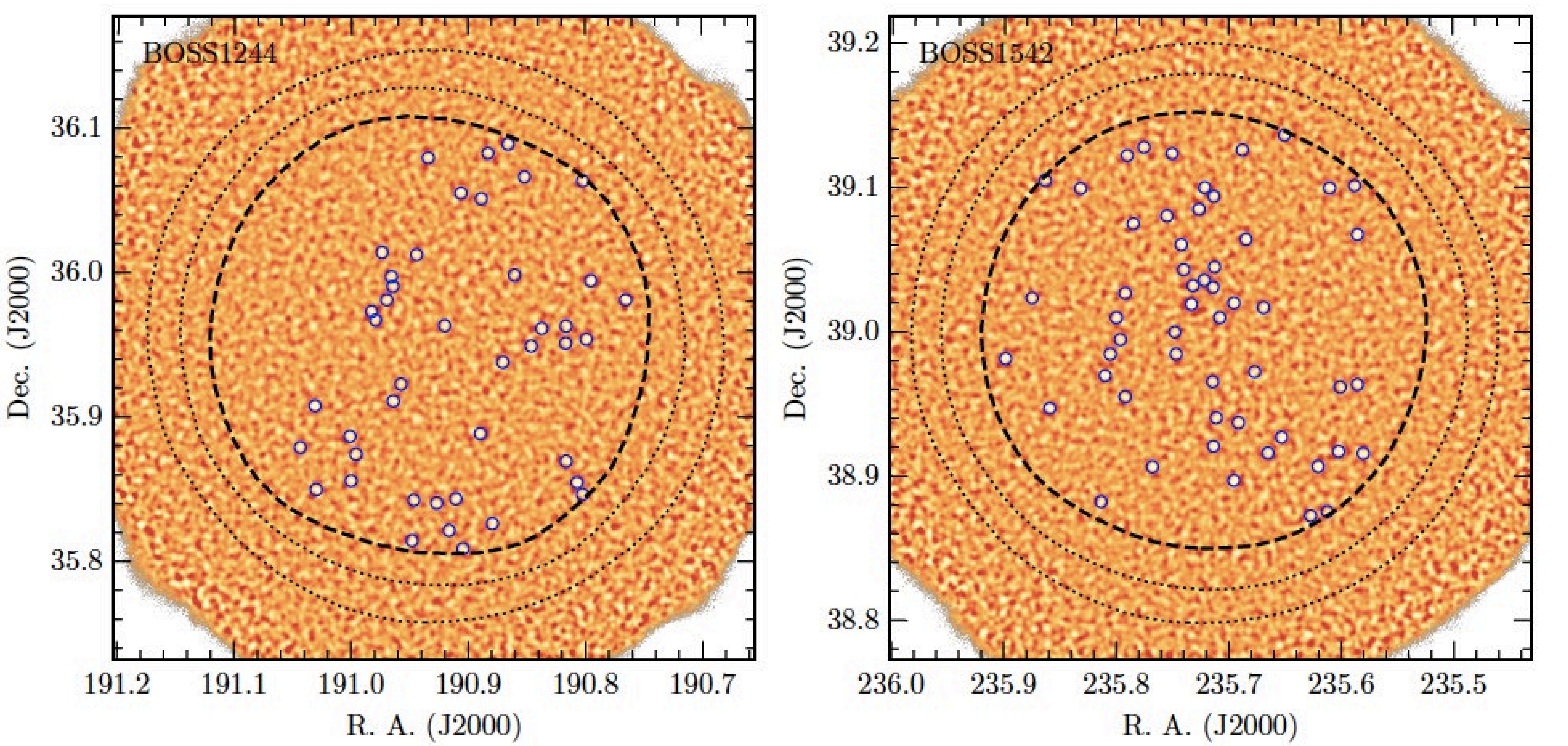




Of 244/223 emission-line objects, 196/175 (+-2) are Hα emitters, giving an overdensity factor of 5.6/4.9 (+-0.3).

Zheng et al. 2021,MNRAS, 500, 4354

SMGs Detectd by JCMT/SCUBA-2 @850um

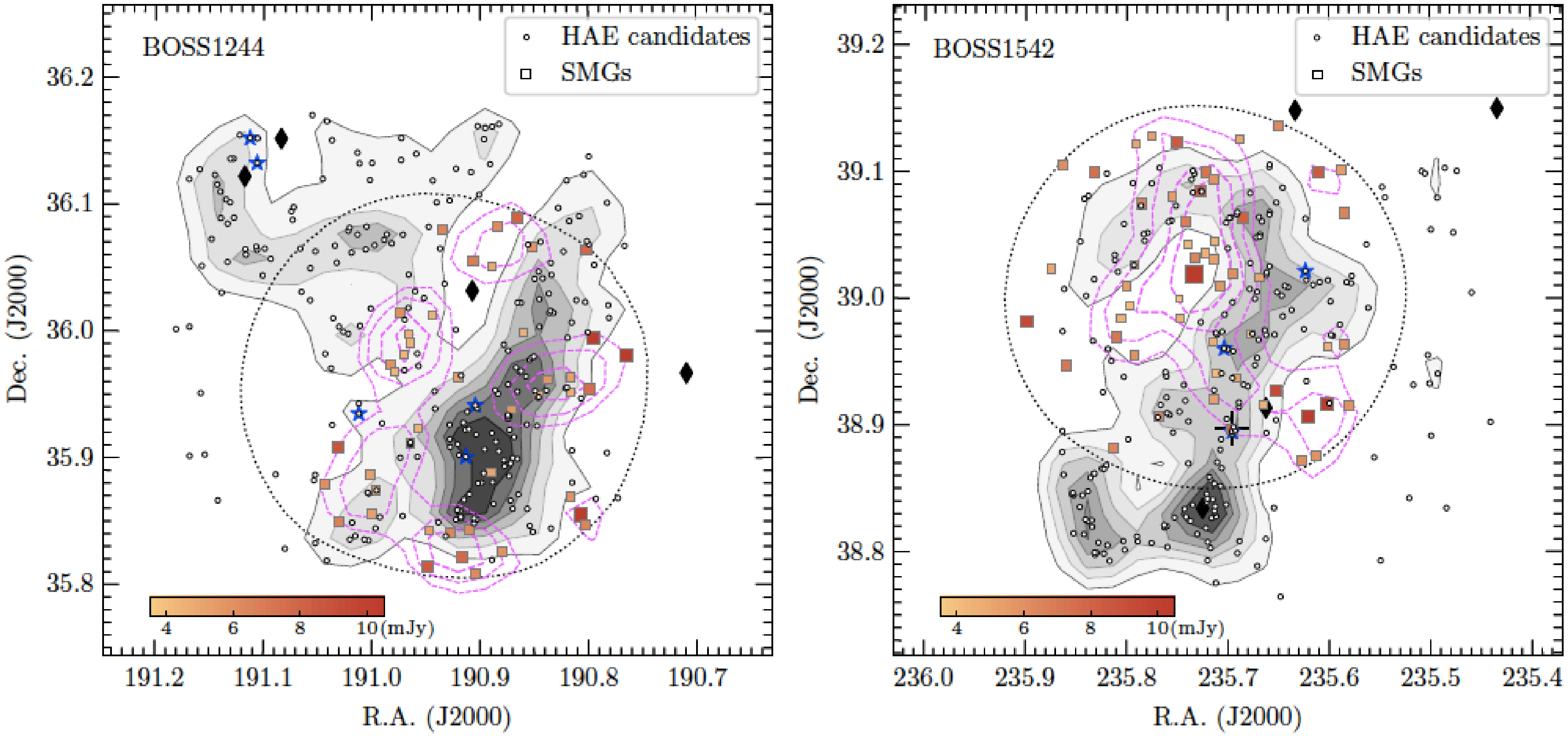


BOSS1244 45 SMGs and BOSS1542 55 SMGs (4σ > 4mJy) ,

SFR>600 Msun/yr at z=2.24

Zhang YuHeng et al. 2022, MNRAS, 512, 4893

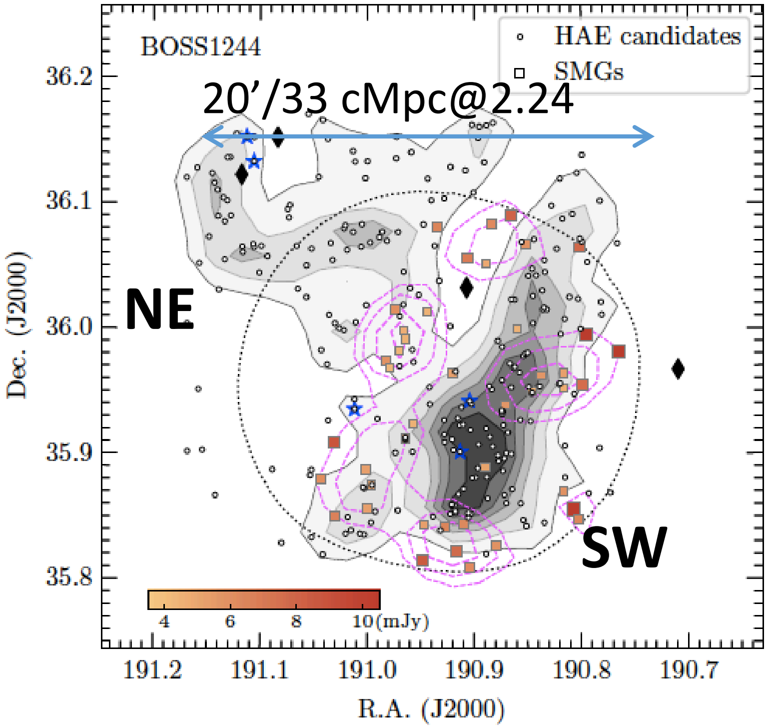
SMGs Mostly Located in the Outskirts

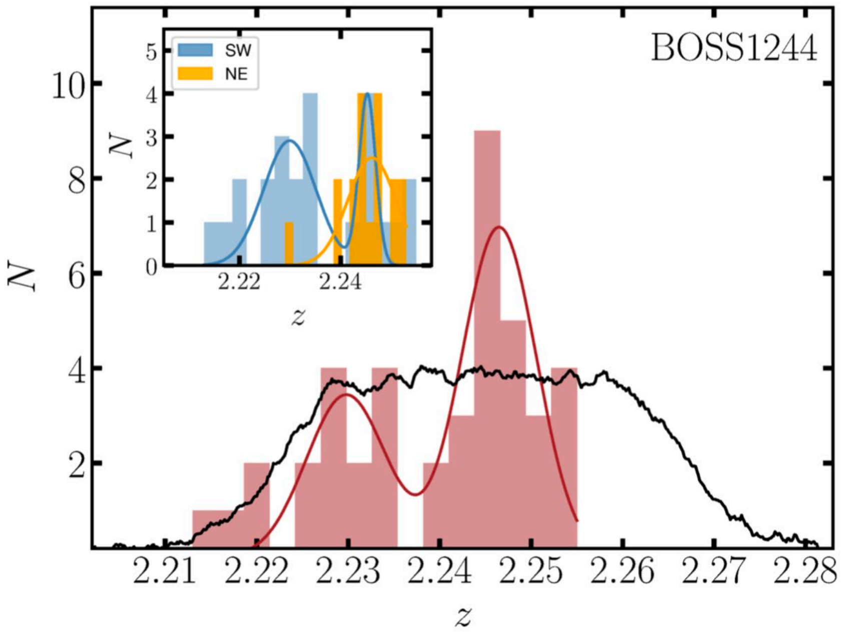


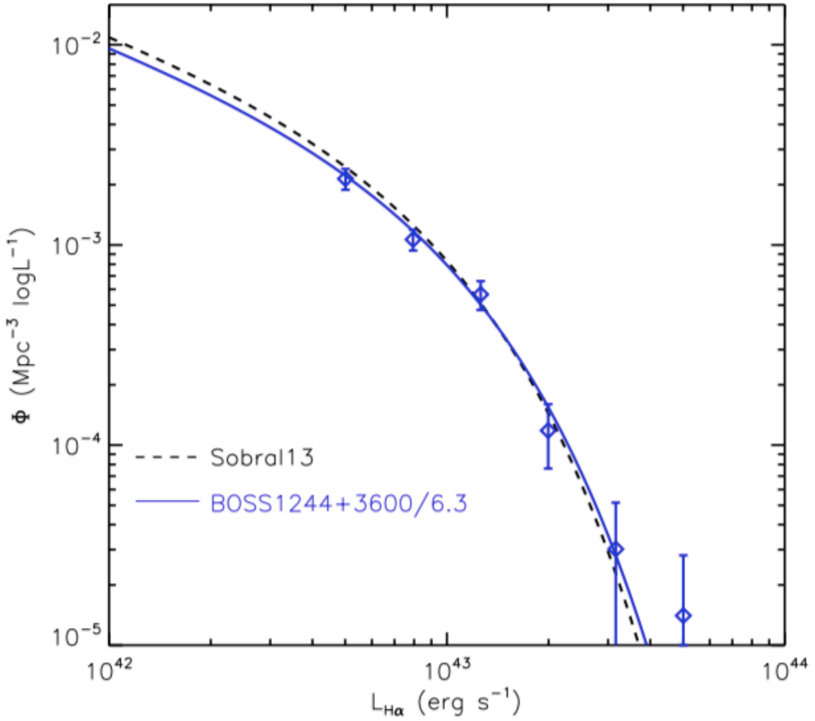
- In the outskirt regime of protoclusters, accretion shock leads to a density increase for baryonic matters (Rost+2021).
- The SMG overdensities found in the outskirts of protoclusters is seen as evidence for the enhancement of gas supply from the cosmic web.

Zhang Y. et al. 2022, MNRAS, 512, 4893

BOSS1244: multiple substructures in merging





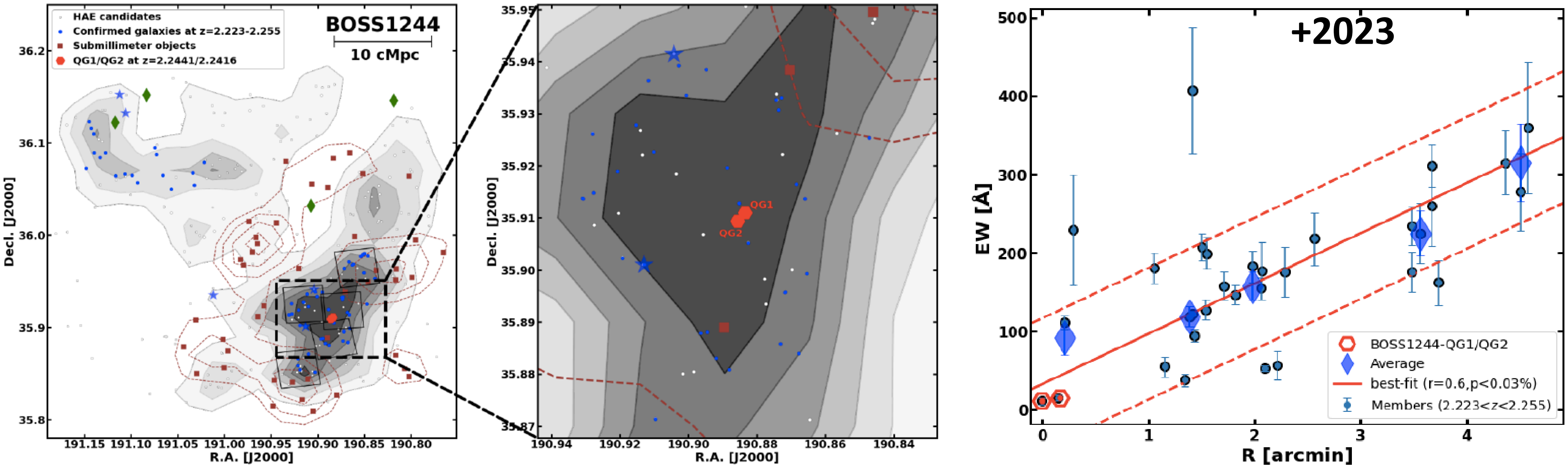


Zheng X.Z.+2021; Shi D.D.+2021

- BOSS1244: two substructures NE &SW; two redshift peaks in SW;
- Velocity dispersion: σ_{SW}~400 km/s@z=2.23 and σ_{NE}~380 km/s@z = 2.25
- A cluster core is in formation through merging of two substructures.

BOSS1244: Quenching by Gravitational/Shock Heating?

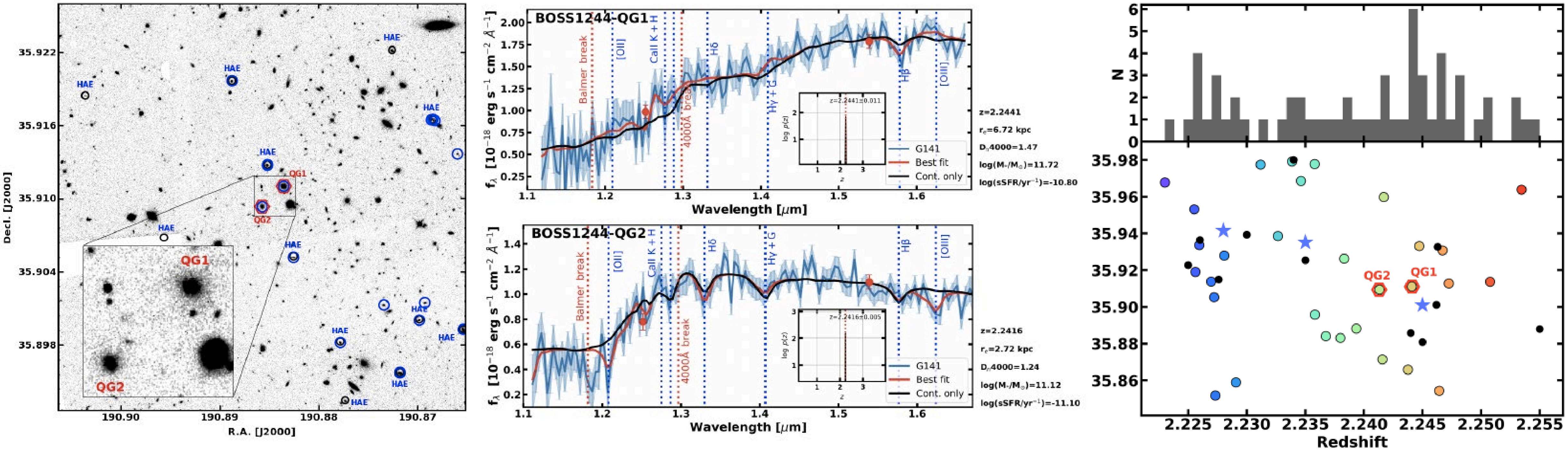
Shi D.D. +2023



- Velocity dispersion: $\sigma_{SW} \sim 400$ km/s and $\sigma_{NE} \sim 380$ km/s.
- A strong SF gradient from the center to the outskirts: **what causes this?**
- Two massive quiescent galaxies detected at the center.

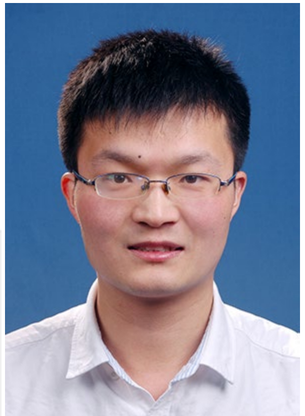
BOSS1244: A Pair of massive quiescent galaxies

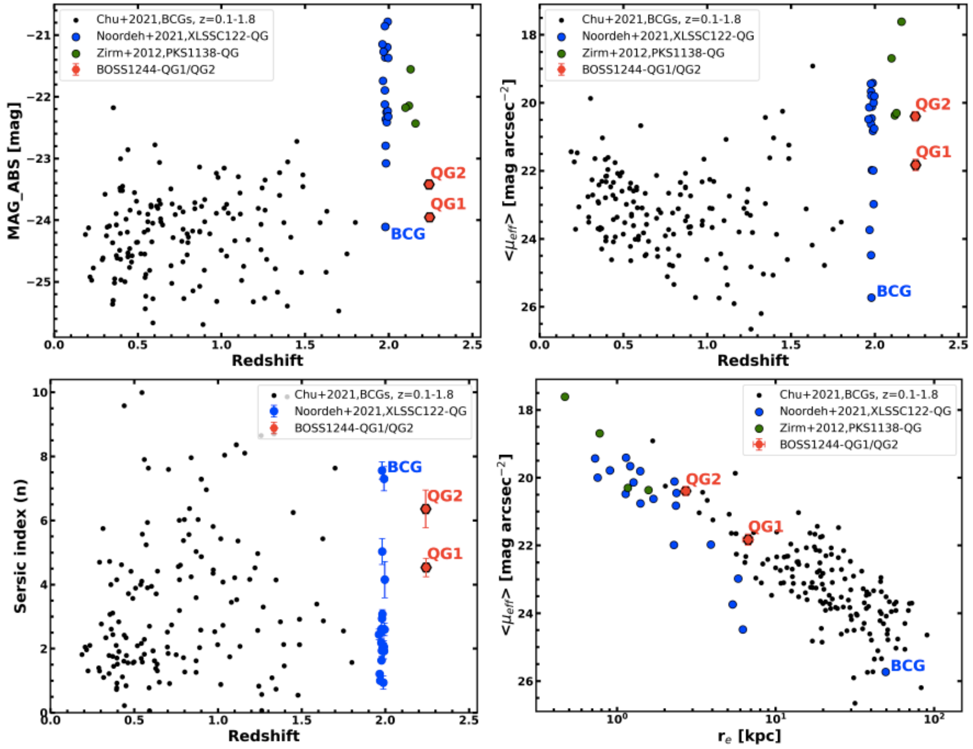
Shi D.D. +2023

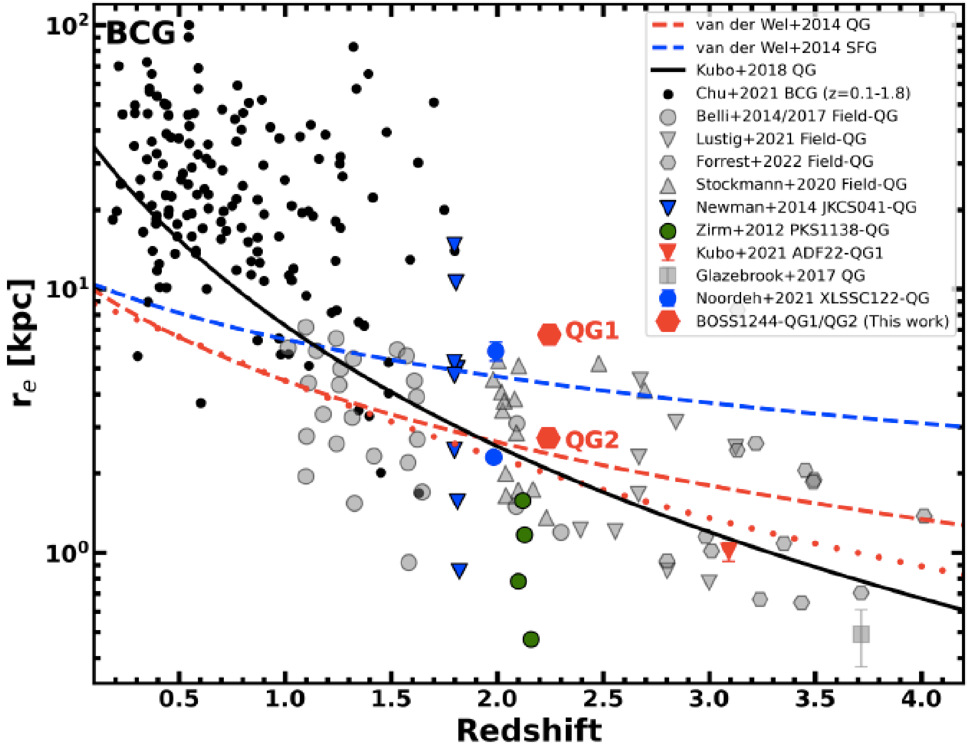


- ➢Velocity dispersion: σ_{SW}~400 km/s@z=2.23 and σ_{NE}~380 km/s@z = 2.25
- ➢QG1: older, more massive logM=11.72 $M_\odot$; QG2: logM=11.12 $M_\odot$

Early Formation of Brighest Cluster Galaxies



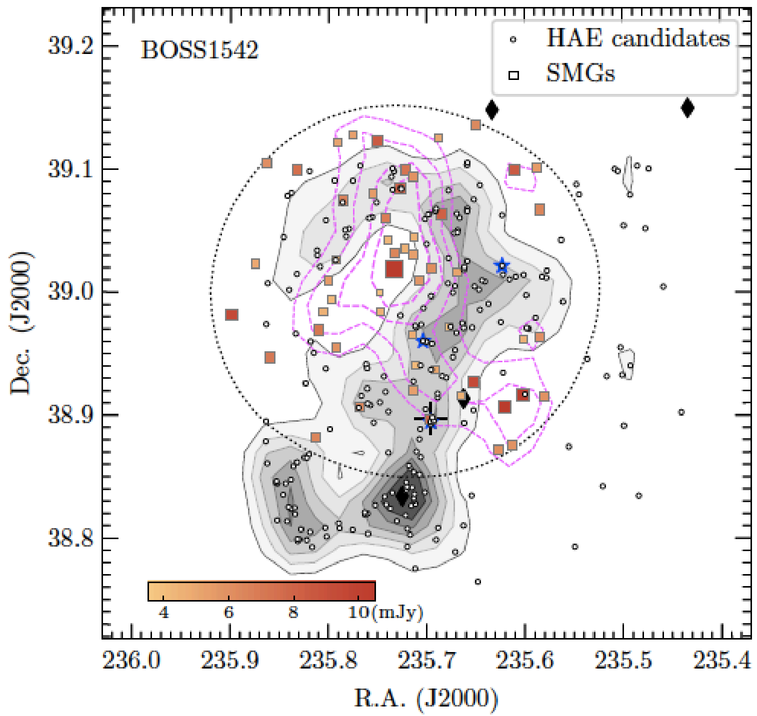


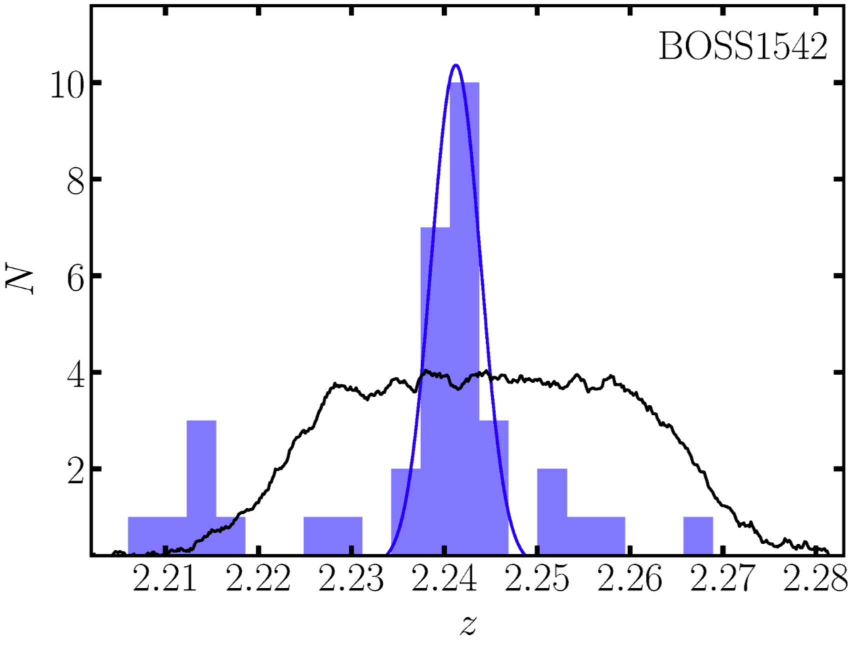


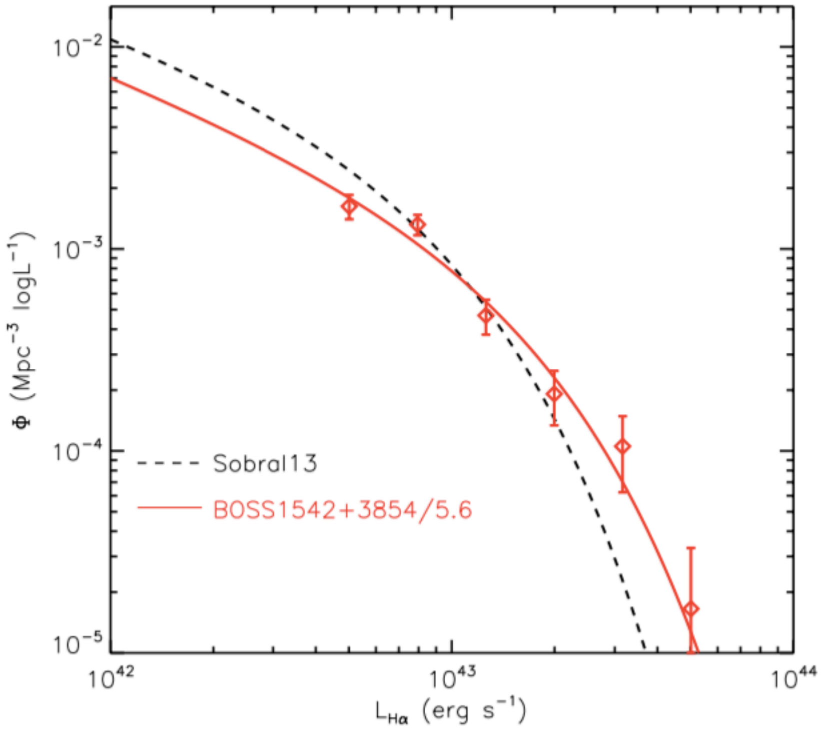
- ➢QG1: older, logM=11.72 Msun, Re=6.8kpc, n=4.5
- ➢QG2: logM=11.12 Msun, Re=2.7kpc, n=6.4

Shi D.D. +2023

BOSS1542: A Giant Filamentary Structure



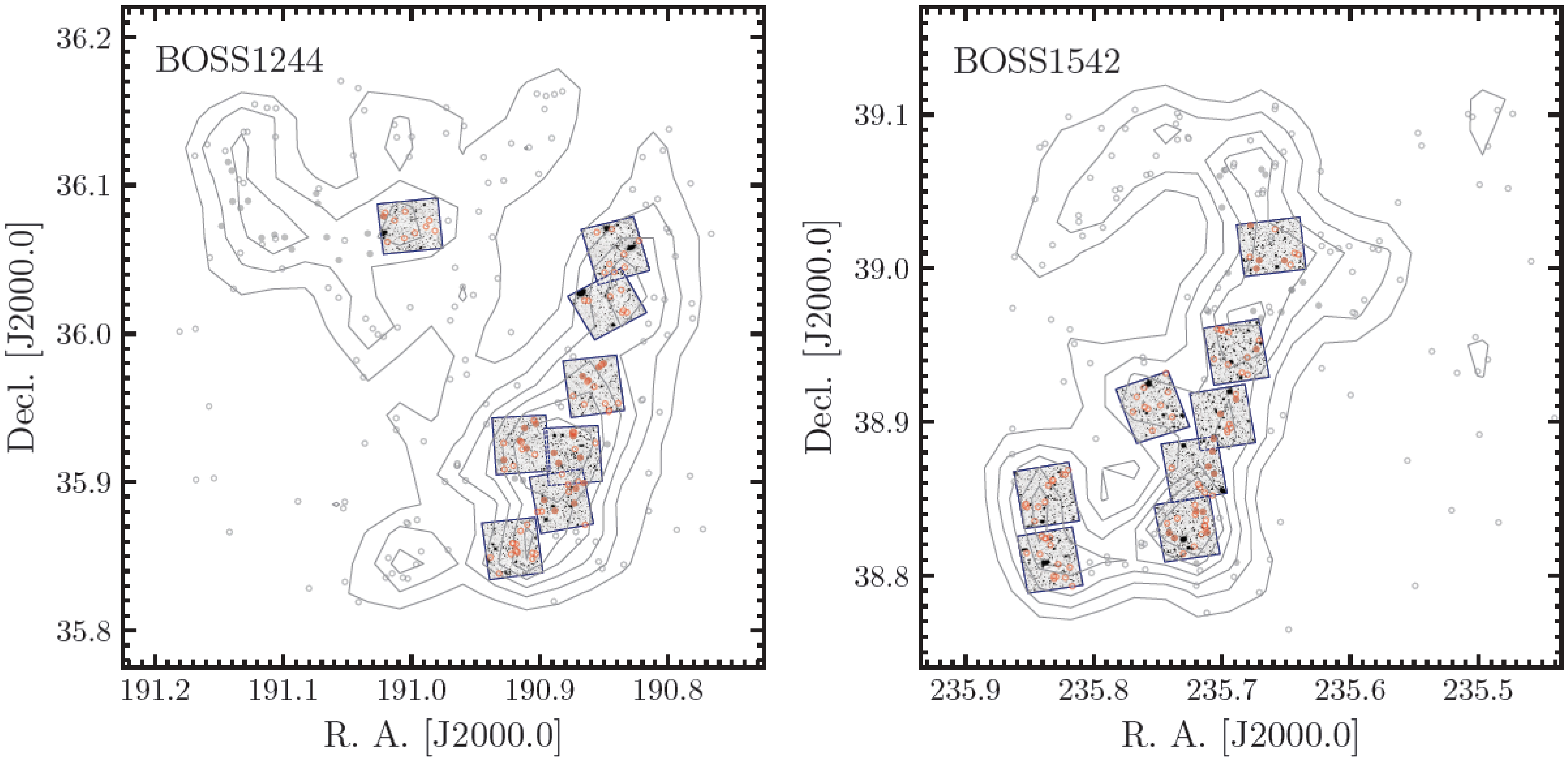




- ➢BOSS1542: the first of such kind discovered ever at z>2 to date.
- ➢Velocity dispersion: $\sigma\sim247$ km/s, a dynamically-cold structure.
- ➢ An excess at the high end of Ha LF, suggestive of an enhancement of SF/AGN.
- ➢ Discovery of an SMG concentration of the highest density, with δ_{gal} ~20.

HST Imaging of Proto-cluster Galaxies

Liu S. + 2023



BOSS1244 & BOSS1542: dynamically cold

BOSS1244

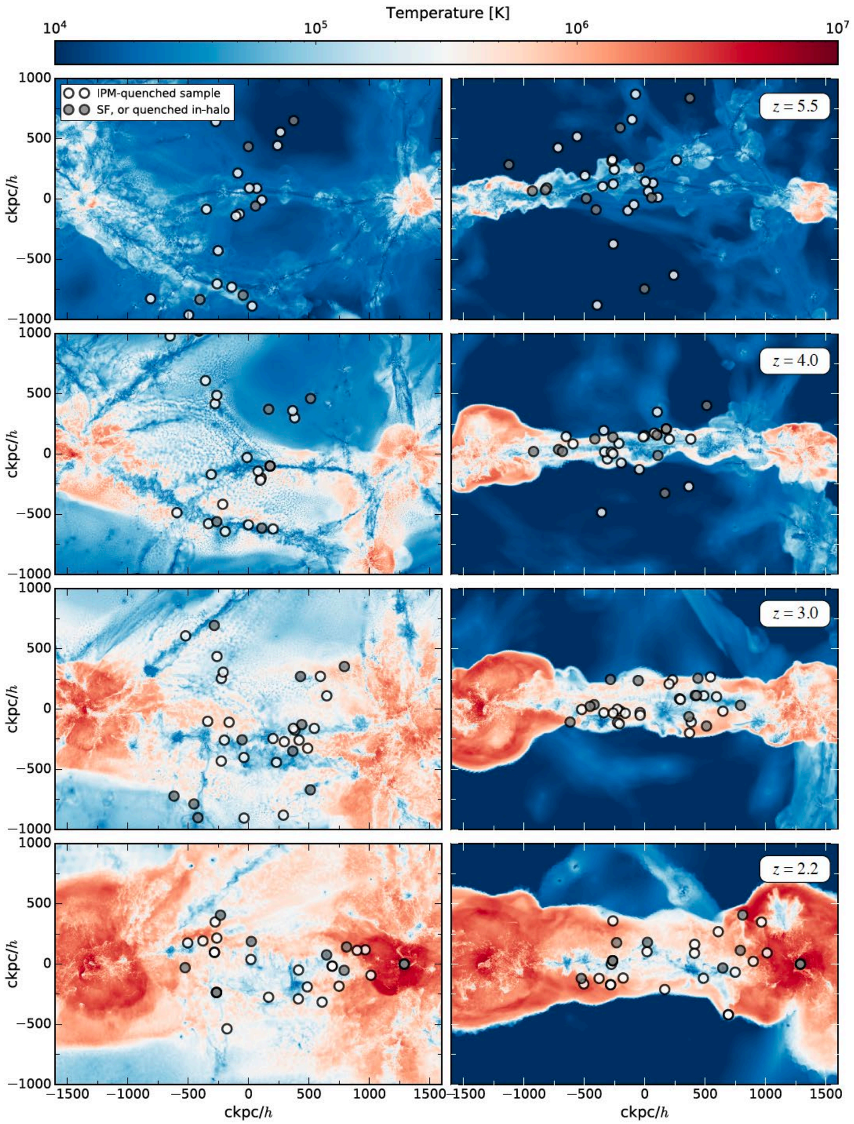
1. overdensity of δ_{gal} ~6.3 over ~30 cMpc, composed of three substructures in merging
2. velocity dispersion of 400 km/s
3. intense star formation
4. a high merger rate
5. A smoking gun ? -- **the SF quenching gradient** in the SW overdensity and **a pair of massive quiescent galaxies**

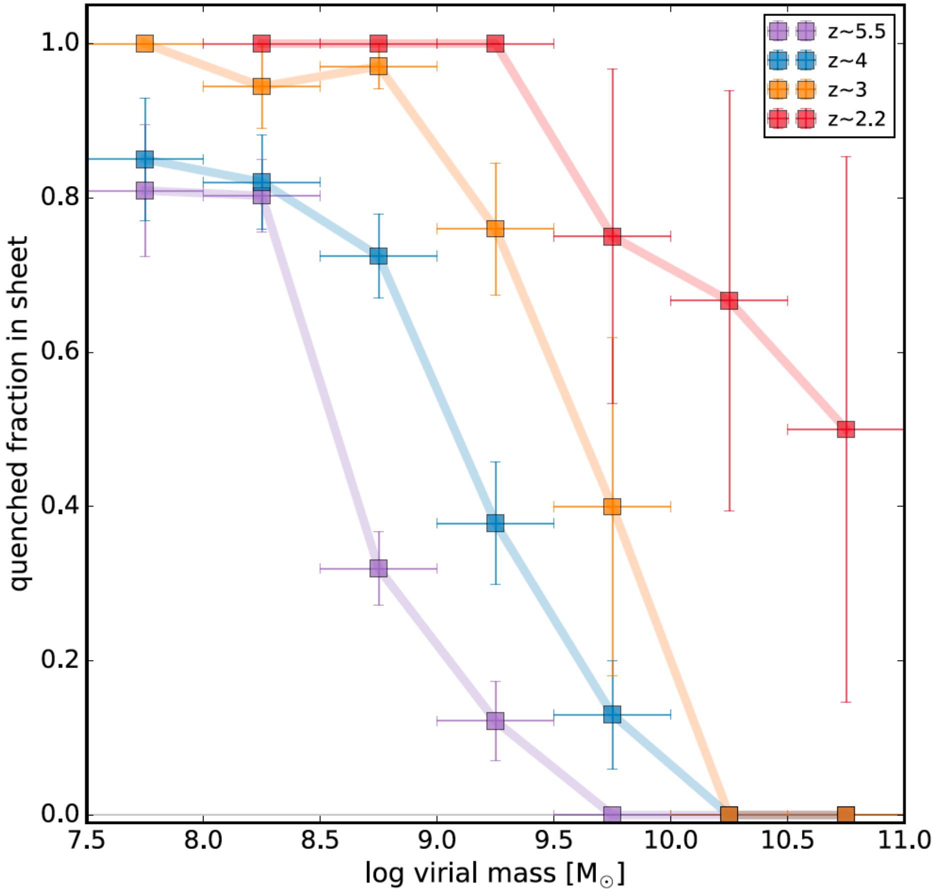
BOSS1542

1. overdensity of δ_{gal} ~5.6 over ~30 cMpc, a giant filamentary structure
2. velocity dispersion of 250 km/s
3. intense star formation
4. even a higher merger rate
5. An SMG overdensity -- enhancement of extreme starbursts, off the HAE density ridges

Zheng X.Z.+2021, Shi D.D.+2021, Zhang Y.+2022; Wang X.+2022; Liu S.+2023, Shi D.D.+2023

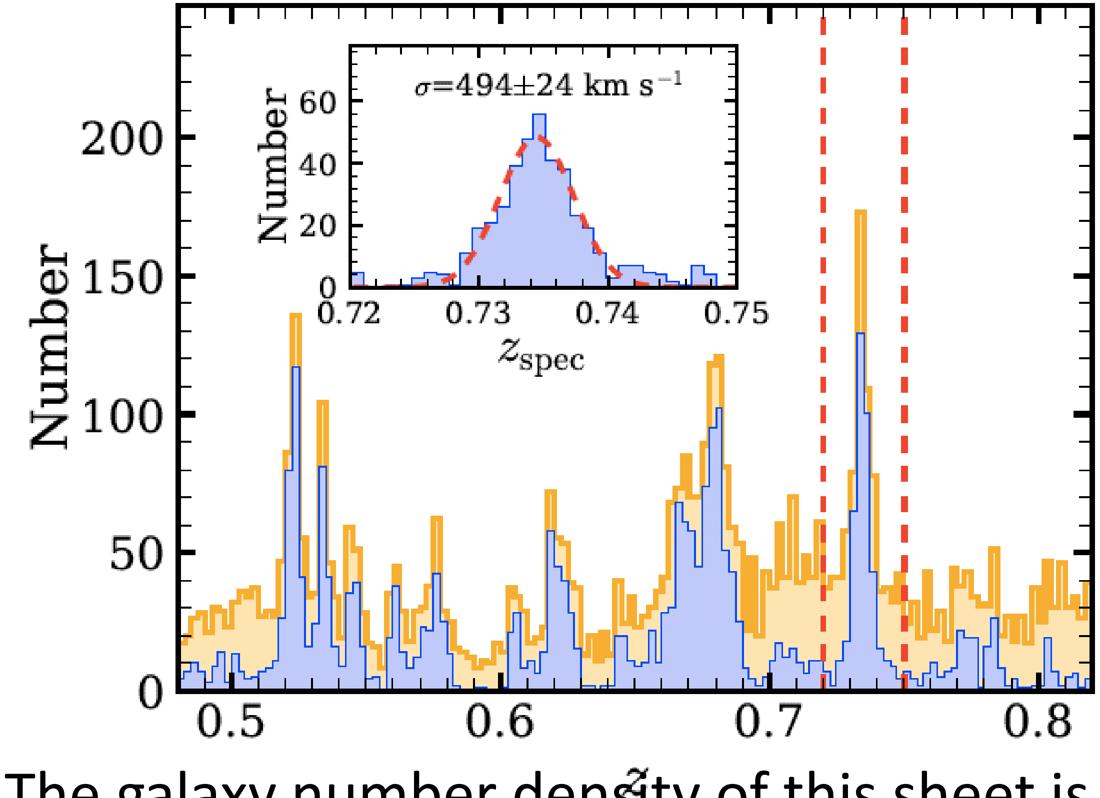
Cosmic Sheets expected to suppress SF in dwarf galaxies



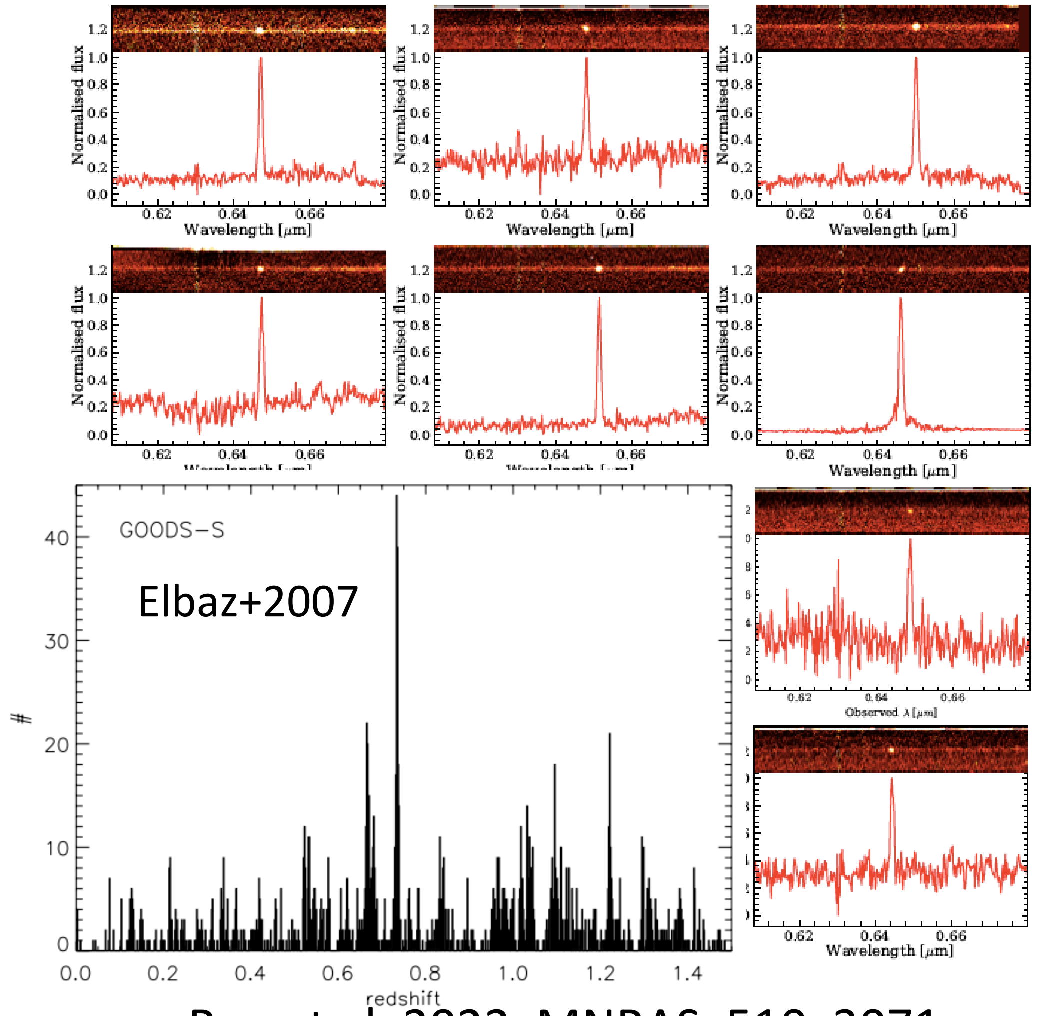


Pasha et al. 2023

A Cosmic Sheet Structure @z=0.735 in E-CDFS

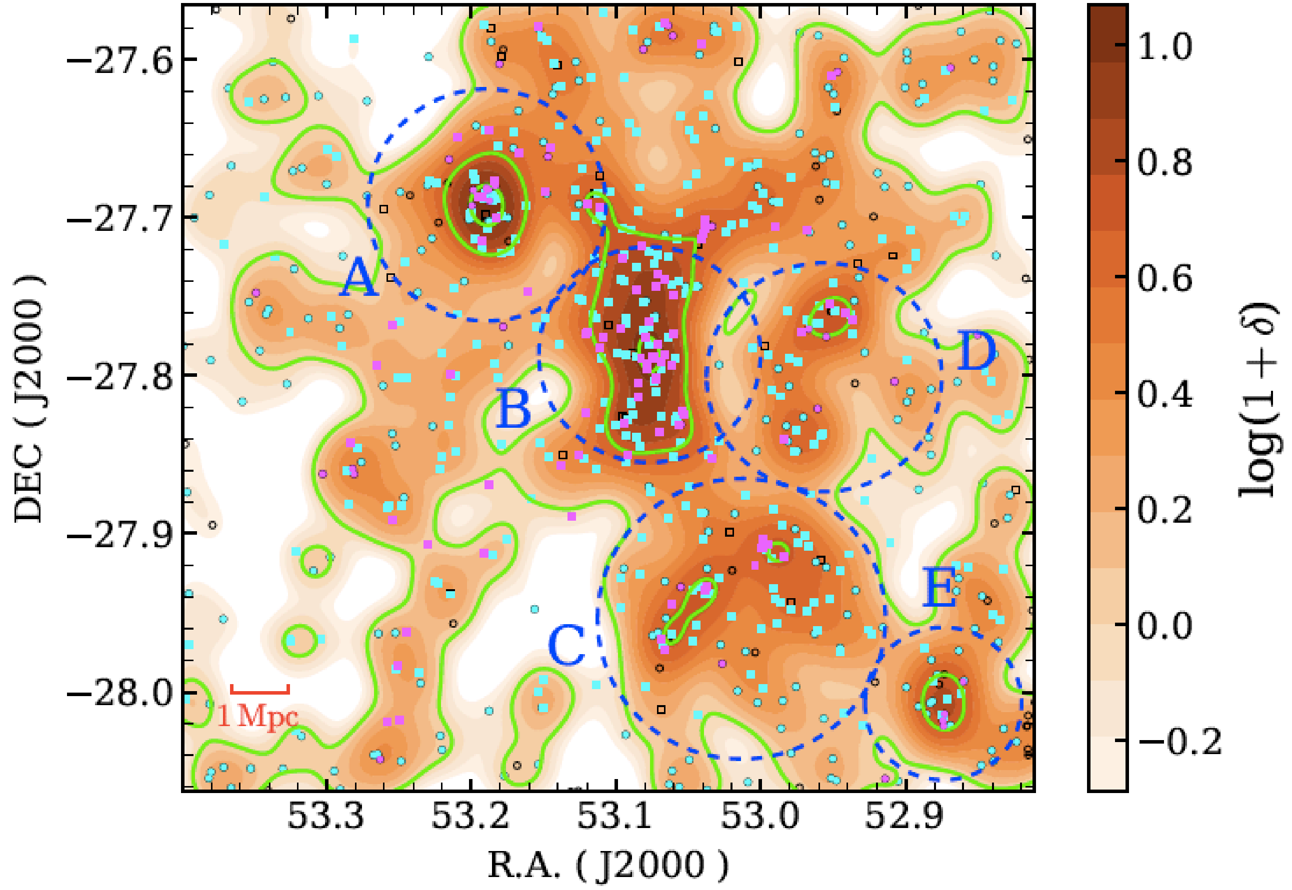


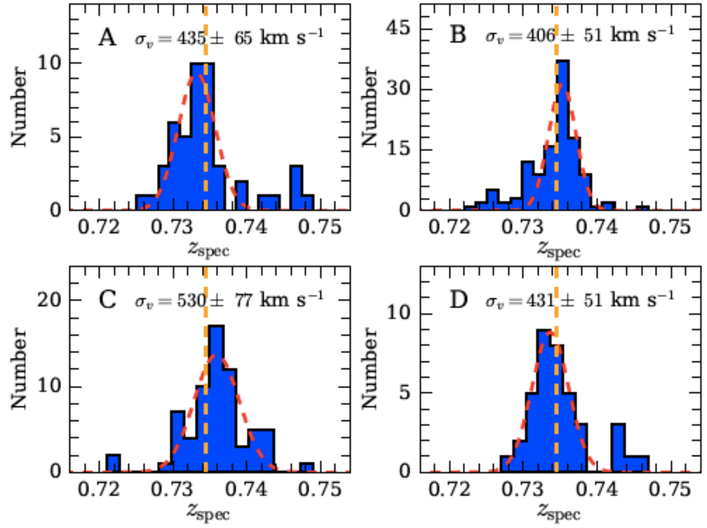
The galaxy number density of this sheet is 3 times that of the general fields. The member galaxies are expected to be acceleraed.



Ren et al. 2022, MNRAS, 510, 3071

Substructures within the z=0.735 Sheet



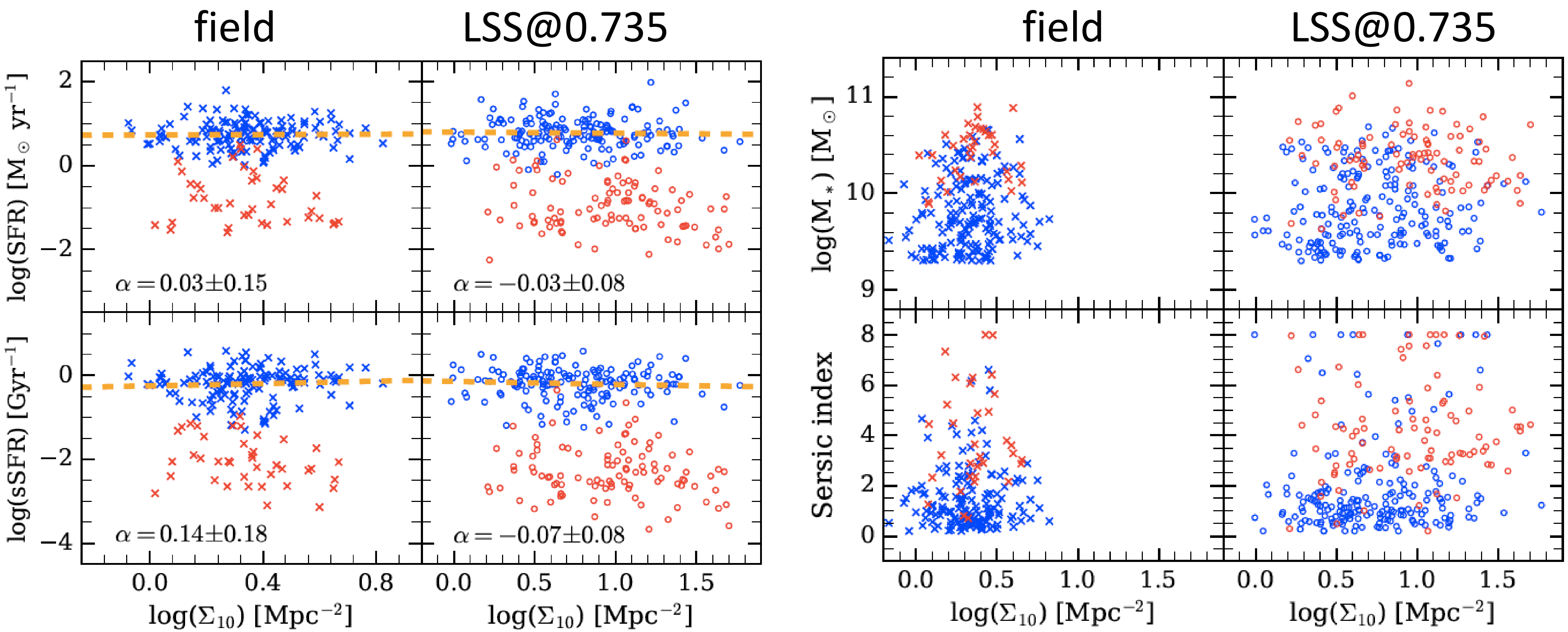


ID	σ_v km s^{-1}	R_{200} (Mpc)	M_{200} ($\times 10^{13} M_\odot$)	$N_{\rm gal}$[a]	C[b]
A	435 ± 65	0.72 ± 0.11	$6.2^{+3.2}_{-2.4}$	58	0.569
B	406 ± 51	0.67 ± 0.08	$5.0^{+2.1}_{-1.7}$	76	0.934
C	530 ± 77	0.87 ± 0.13	$11.2^{+5.6}_{-4.2}$	64	0.688
D	431 ± 51	0.71 ± 0.08	$6.0^{+2.4}_{-1.9}$	42	0.595

[a] Number of member galaxies with spec-z+phot-z within $r/R_{200} < 2$.
[b] Spec-z completeness within $r/R_{200} < 2$.

Over 23x23x39 cMpc^3 at z=[0.73-0.74], there are 710 galaxies with R<24 (412 spec-z, 298 phot-z)

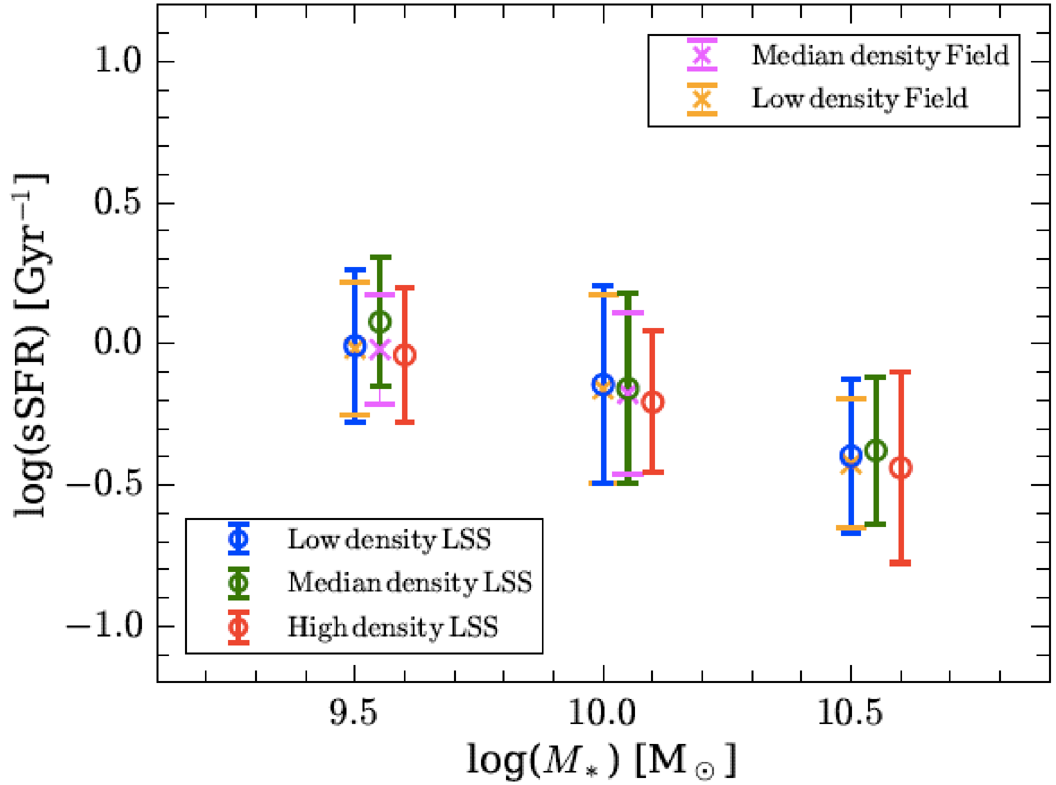
Galaxy SFR: No Dependence on the local density

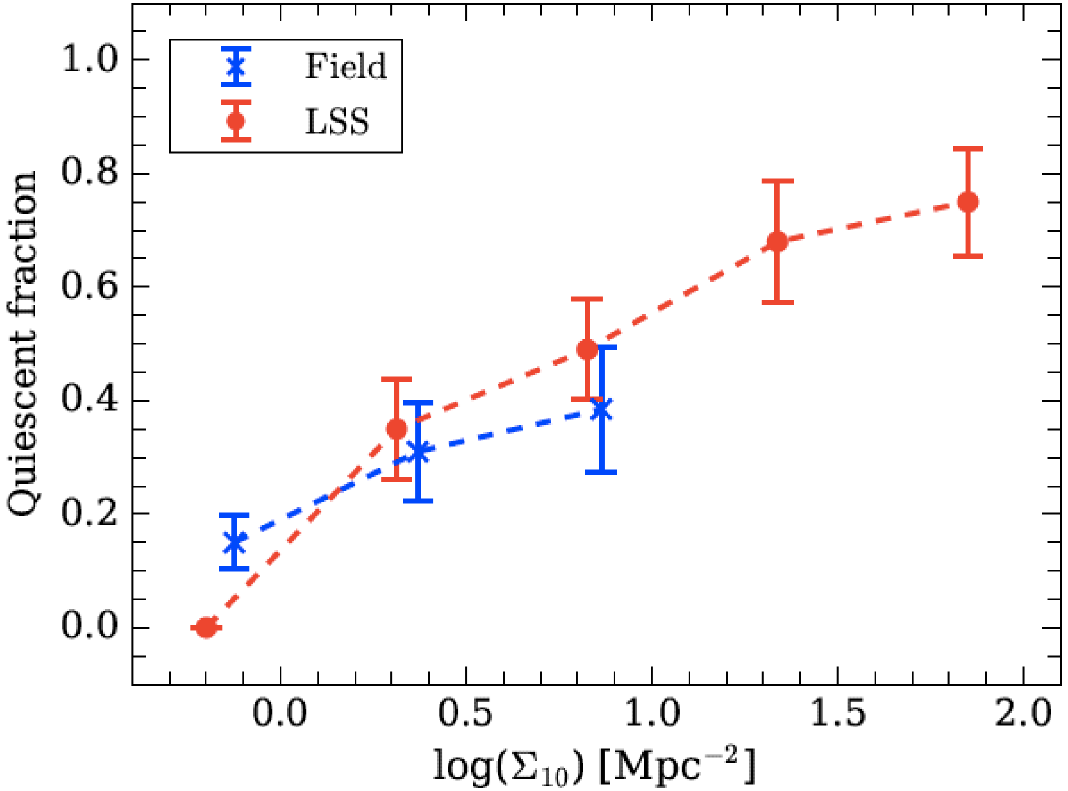


No difference is found for galaxies between the field and the LSS at z=0.735 in terms of SFR, SSFR, M* and Sersic index.

What regulate SF Quenching?

Ren et al. 2022, MNRAS, 510, 3071





The z=0.735 Sheet lacks hot gas (ICM) for quenching via ram pressure or stripping. Local density-related processes/quantities control quenching.

What are the dominant quantities for the growth of galaxies?

- Galaxy mass appears as a dominant quantity for forming the scaling relations of galaxies (M_{halo}-M^*, SFR-M^*, Σ_{gas}-Σ_{SFR}, M_{BH}-M_{bulge}, $Z/Z_{\odot}$-M^*, Re-M^*).
- Galaxy growth is driven by star formation and galaxy mergers . What control these processes regulating the growth?
- **The cosmic environment** refers to the available matter reservoirs and surrounding tidal field, and determines matter flowing situation: **nourishing** vs **starving** .
  - ✓ Dwarf galaxies may grow to massive ones in a nourishing site, but cease star formation once entering a starving place (e.g. hot haloes).
  - ✓ Massive galaxies can still grow through star formation fueled by gas from the cosmic web, or galaxy mergers in dense and dynamically-cold environments.
- **What key quantities/parameters quantify the degree of nourishing (or starving)?**
  - ➢ **Overdensity factor + connectivity measure the available matter reservoirs.**
  - ➢ **Dynamical state of (sub)structures deeply impacts on gas cooling and fueling (thereby star formation), and the structural evolution of galaxies via merging.**

Summary

- Extremely massive galaxy protoclusters at cosmic noon are ideal labs to explore the connections between galaxy and structure formation.
- The spatial offsets between SMG and HAE density peaks are likely evidence for the accretion shock in the outskirts of protoclusters.
- A first galaxy SF gradient over a scale of ~6 cMpc at $z>2$, and a pair of massive quiescent galaxies at the center of BOSS1244
- The enhancement of galaxy mergers is favored by the dynamical cold state of BOSS1244 and BOSS1544 protoclusters.
- Large-scale (global) environment as well as the local environment both regulate star formation and quenching in galaxies.