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The social life of galaxies:

linking environment and star formation at high-z

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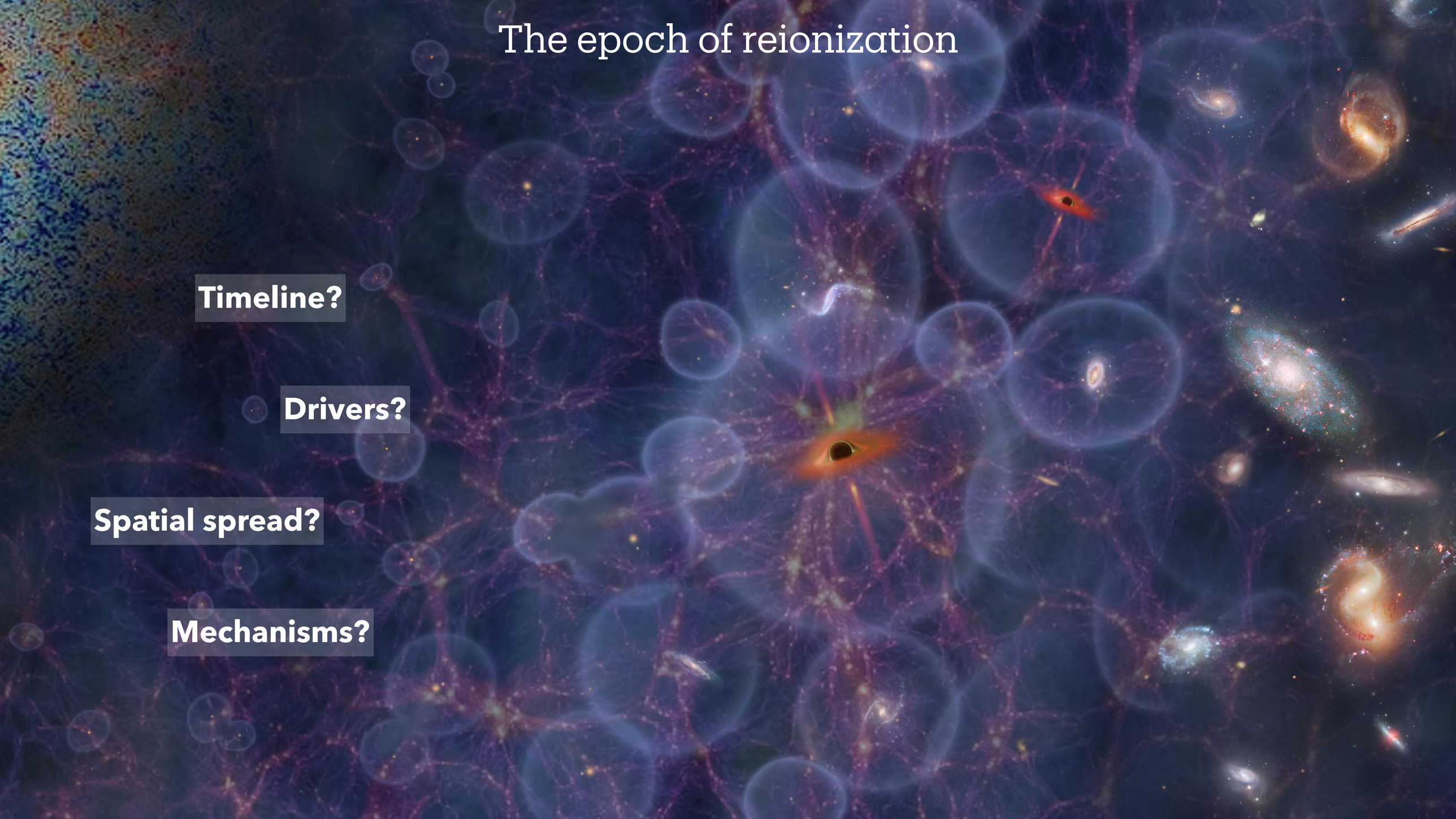
with Kirsten Knudsen and the RECAP team

Credit: Artist's conception of cosmic reionization
(Jingchuan Yu, Beijing Planetarium).

The epoch of reionization



Timeline?

Drivers?

Spatial spread?

Mechanisms?

The epoch of reionization

Are galaxies in denser environments more efficient at reionizing?

Timeline?

Drivers?

What are the properties of companion galaxies?

Spatial spread?

Who is dominating the large UV bright bubbles?

Mechanisms?

What's the impact of mergers?

The epoch of reionization

Are galaxies in denser environments more efficient at reionizing?

Timeline?

Dri

Impact of galaxies and AGNs on their surrounding environment (CGM), and the other way around, at z > 4

pperties of alaxies?

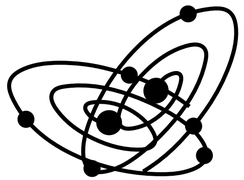
Spatial spread?

Who is dominating the large UV bright bubbles?

Mechanisms?

What's the impact of mergers?

Correlations between mergers and reionization?



$z < 3$

- Enhancement of **SFR** (off-centre, depends on galaxy types)
- **AGN** excess

- Enhancement of **SFR** for ~1Gyr
- Triggers **AGN peak activity** (higher AGN excess, high-L AGNs, …)
- Diluted **metallicity**
- Irregular / disturbed **morphologies**

Correlations between mergers and reionization?

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$z \geq 4$ (and EoR)

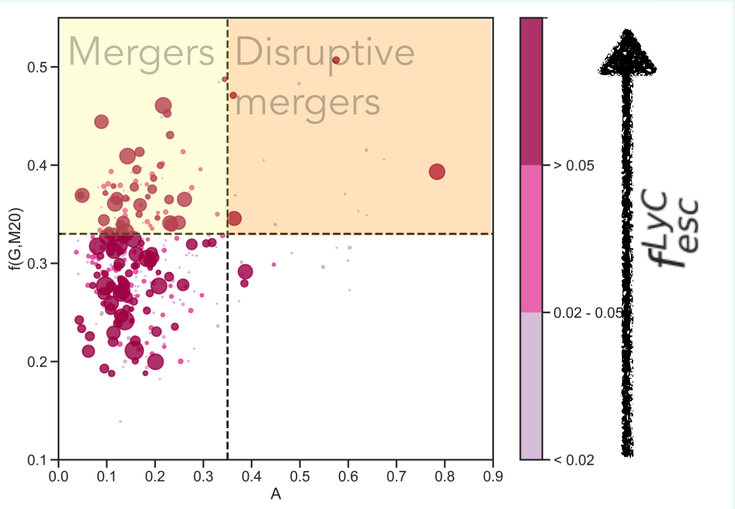
?

- Less effects from mergers on galaxy evolution at higher z? [e.g., Wilson+19, Dalmasso+24]
- Mergers account for more than 50% of star formation at z > 5? [e.g., Duan+25]
- Production and escape of ionising photons?

No correlations between mergers and reionization?

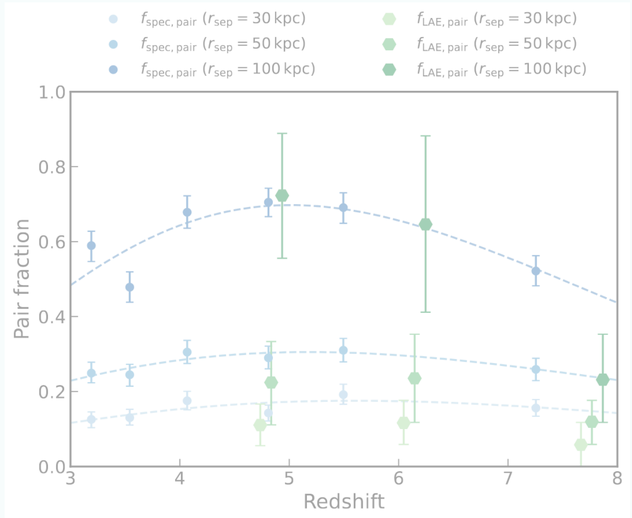
[Mascia et al. 25]

- 436 low-mass star-forming galaxies at $5 \leq z < 7$ in JWST surveys
- No correlations between merger morphology features and $\xi_{\rm ion}$ or $f_{\rm esc}$



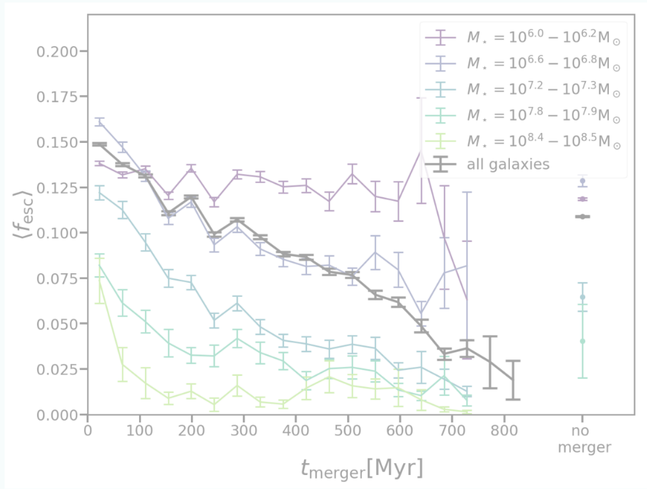
[Puskas et al. 25]

- Mass-complete sample of 2000 galaxies at $3 \leq z < 9$ in JADES
- Moderate sSFR enhancement (12% at < 20 kpc), no AGN excess
- No LAE excess → interactions not efficient at enhancing Lyα production and escape



[Kostyuk & Ciardi 25]

- 10^5 galaxies at $5 \leq z < 10$ in TNG50 simulation
- Increase of $f_{\rm esc}$ immediately after merger
- Galaxies in overdense regions have higher $f_{\rm esc}$ independently of mergers (higher gas inflows)



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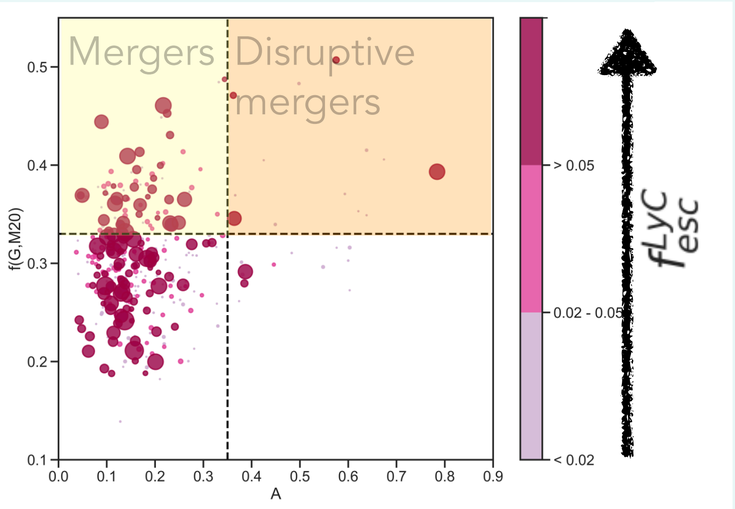

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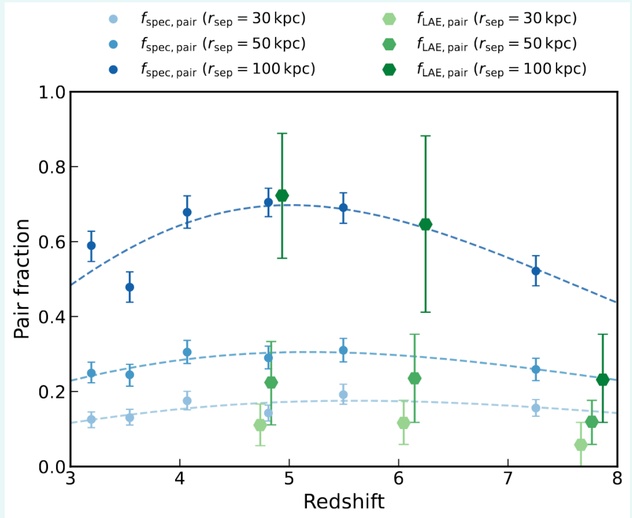

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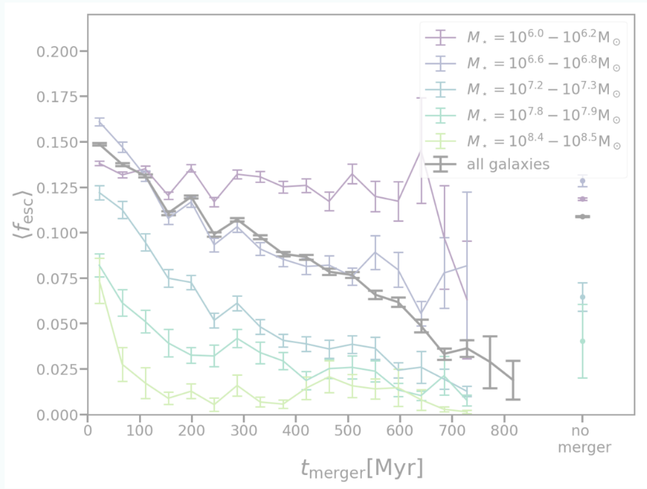

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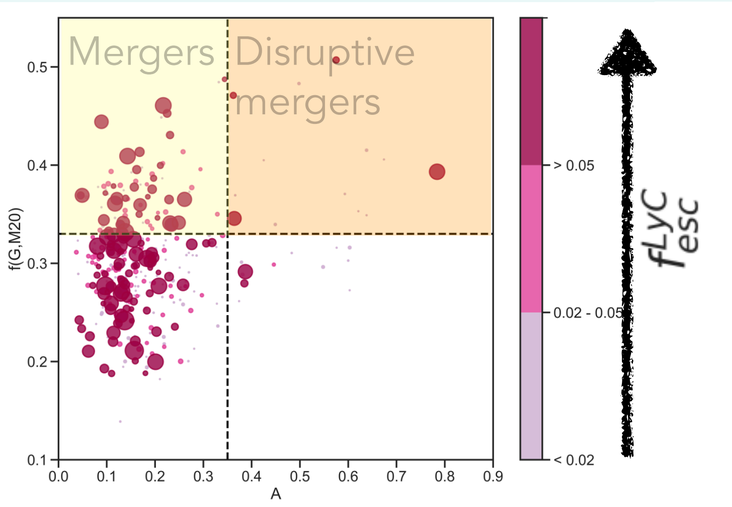

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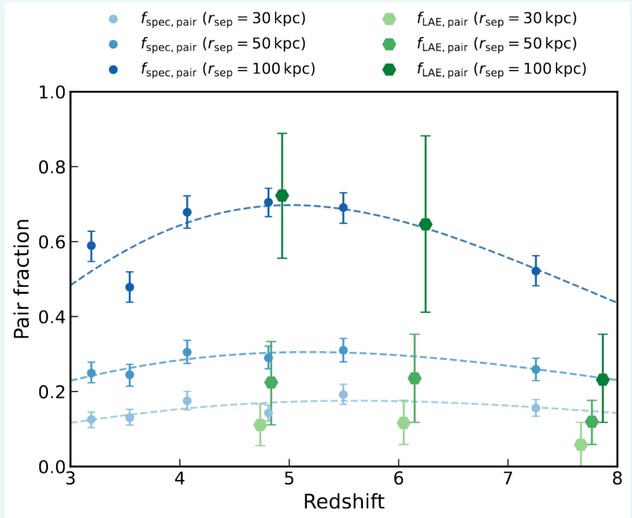

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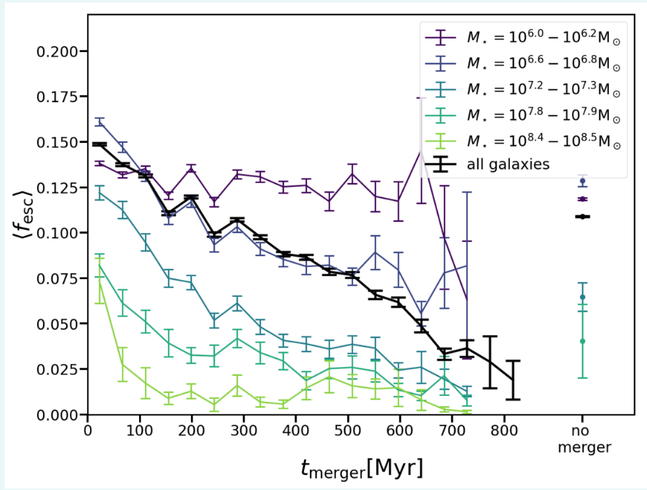
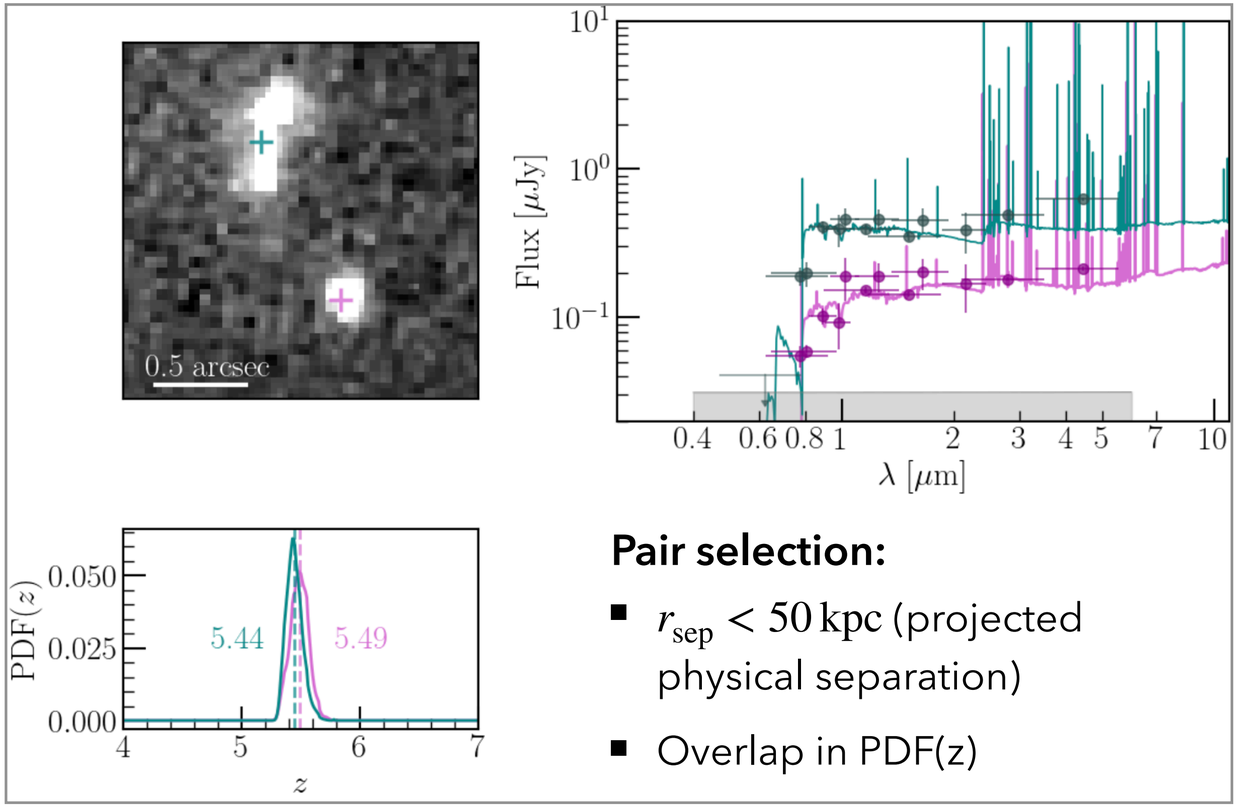


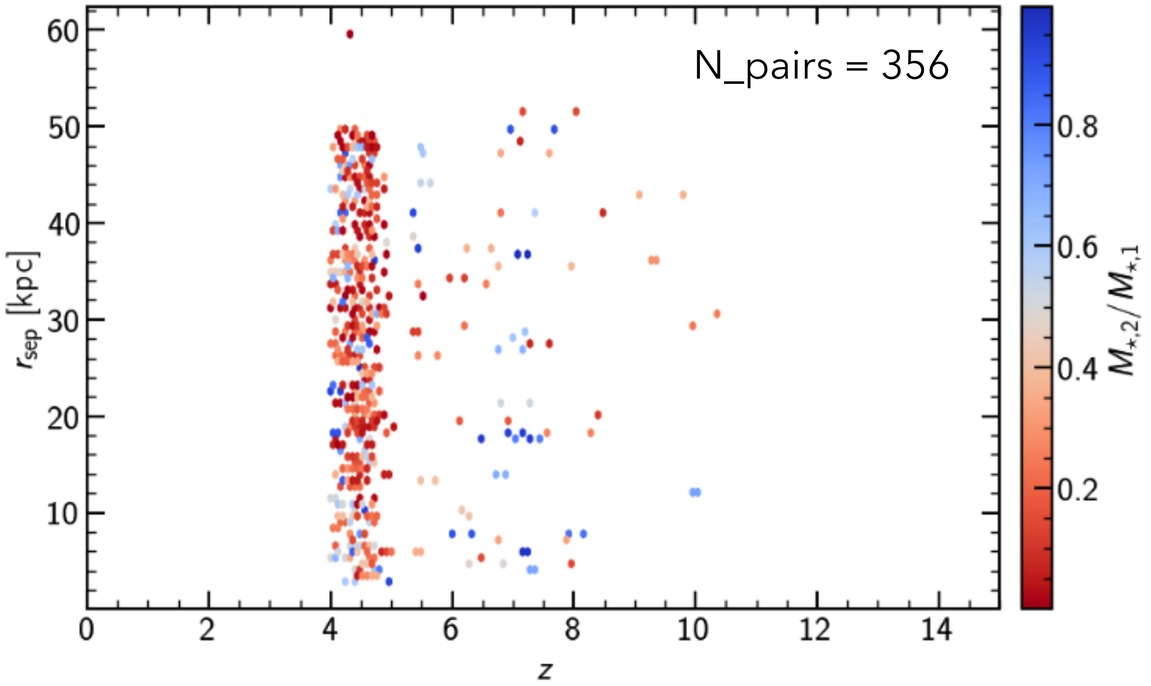
Selection of pairs at z > 4 in COSMOS-Web

- **Why COSMOS-Web?**
  - Wide JWST photometric survey => various environments, large-scale info, extensive obs in the field
  - Spectro data incoming (grism COSMOS-3D, and high-z JWST programs)



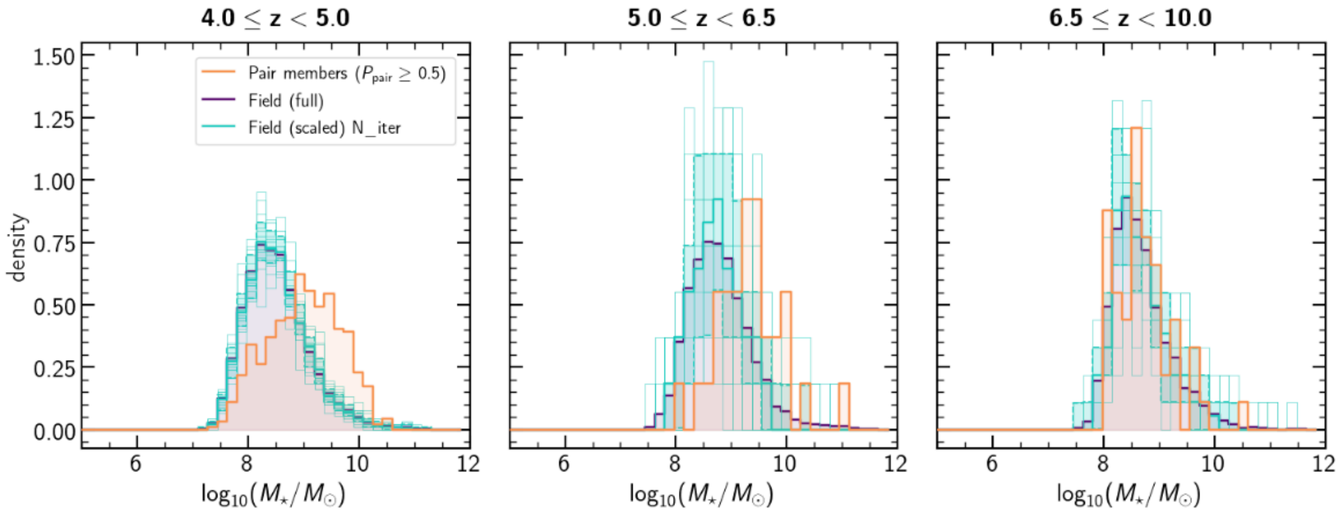
Pair selection:

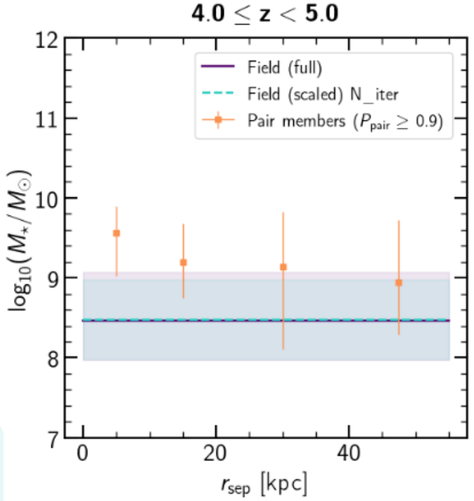
- $r_{\rm sep} < 50\,{\rm kpc}$ (projected physical separation)
- Overlap in PDF(z)



Properties of pair members

$M_\star$





Does it depend on the separation distance ?

SFR

Properties of pair members

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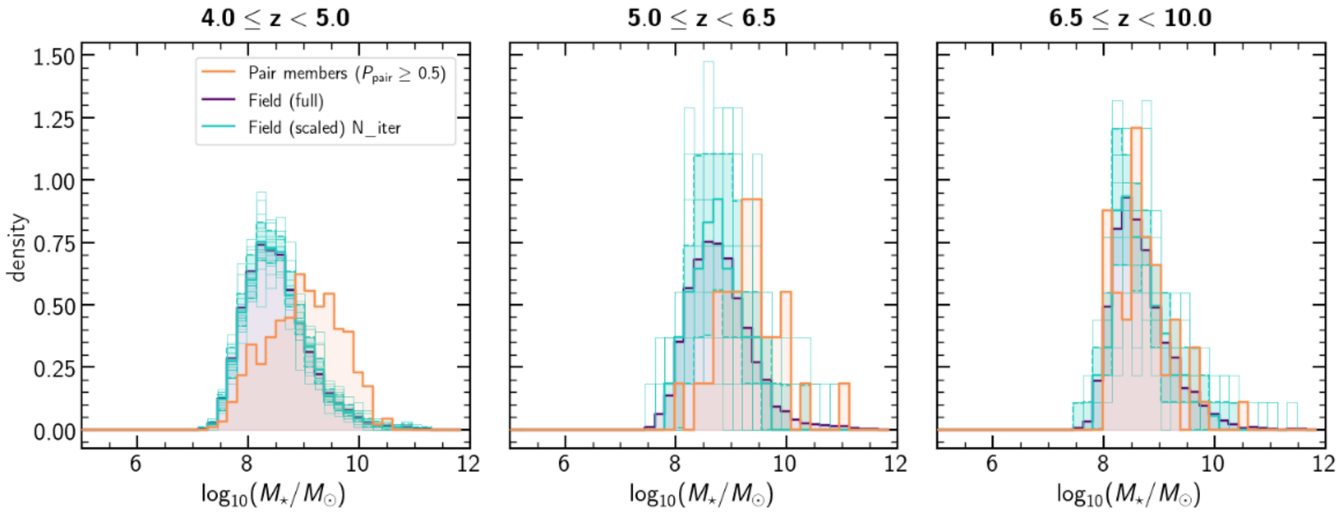
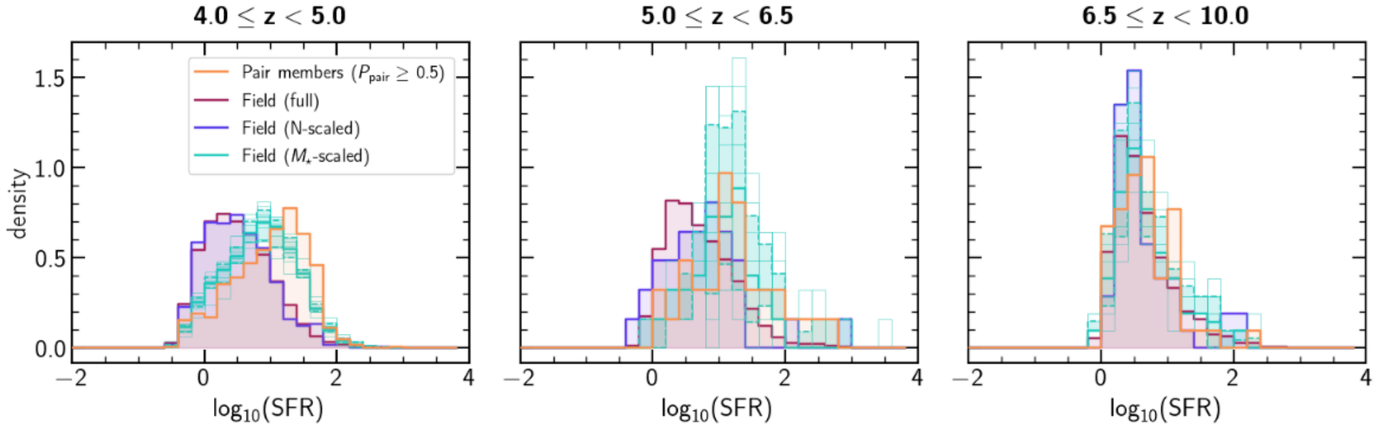


SFR



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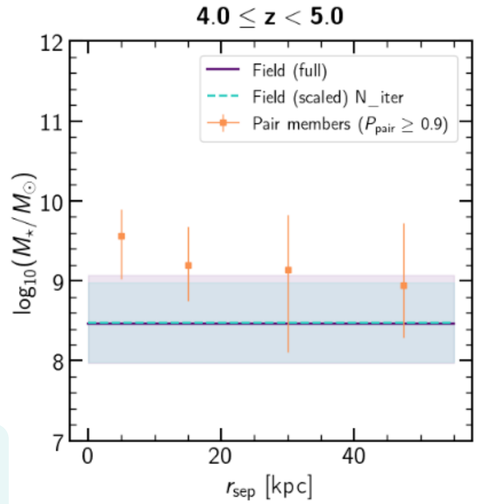
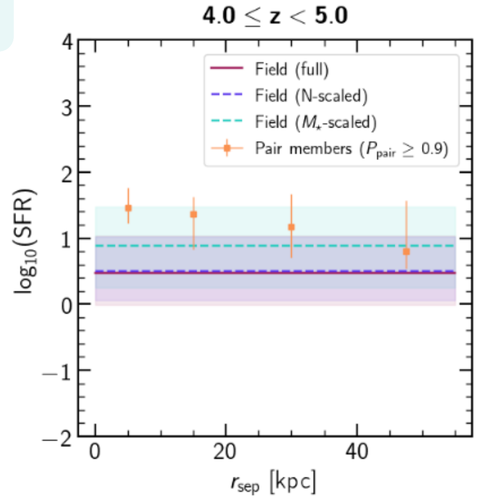
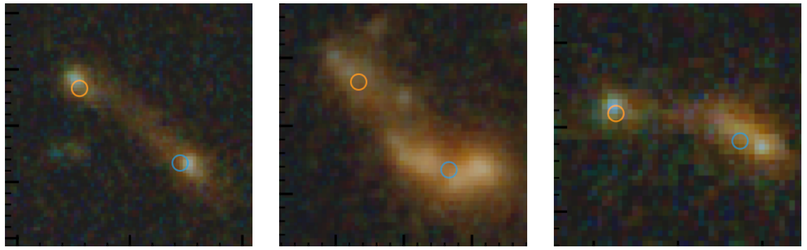


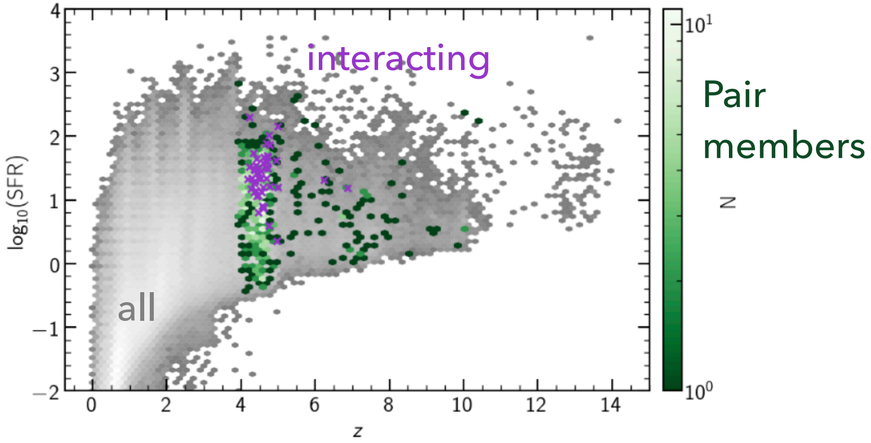


- Pair members are more massive, and have a higher SFR than field galaxies. This effect is greated at smaller separations (r < 10 kpc). No correlations with other properties (dust via E(B-V), morphology, radius).

What is in the pair sample at z > 4?

- **Interacting pairs with extended gas emission:** lie in the high-mass, high-SFR locus
  - If morphological disturbance, could clear LyC escape channels and trigger starbursts

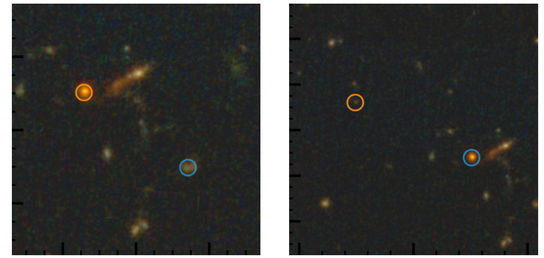




- **Minor mergers:** low-mass companions of massive galaxies lie in low-SFR locus
  - Low-mass galaxies could be more efficient at reionising when they are in the field, not in dense regions

- **Major mergers**
  - Usually more disturbance when similar masses

- **Pairs with AGNs**



Next? ALMA proposal ideas

1) ALMA observations of a z > 4 pair sample

- Are companion galaxies of massive galaxies gas-poorer (or gas-richer)? Are they more star-forming?
- Obs of dust continuum (and lines?) to get $M_{\rm dust}$, $M_{\rm gas}$, $\rm SFR_{[CII]}$ …
- Control galaxies from existing ALMA obs in COSMOS-Web

Establish the method with a robust 4 < z < 5 sample → Get statistics about SFR/gas enhancement just after the EoR → Apply this method to higher-z data → Ask for JWST obs, and get EoR properties

Next? ALMA proposal ideas

1) ALMA observations of a z > 4 pair sample

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- Control galaxies from existing ALMA obs in COSMOS-Web

2) ALMA deep observations of systems QSO + companions

- Have companions enhanced SF / ionising power? Do they have cleared channels for ionising photons to escape? Who is dominating the system?
- Obs of the resolved ISM by [CII] maps, molecular gas content, …
- Exists in the literature for individual systems, but low statistics

If you have any favorite high-z QSO+environment system you would like to observe, tell me!

Summary

Are galaxies in denser environments more efficient at reionizing?

What are the properties of companion galaxies to quasars?

What's the impact of mergers at z > 4?

- Properties of **close pairs at z > 4** in COSMOS-Web: more massive and higher SFR
- Follow-ups in radio/optical/IR of interesting systems or sample
- Take a look at simulations!

Your thoughts/ ideas?

- Pair selection?
- Follow-up ideas?
- Synergies with your work?

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RECAP erc synergy grant

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European Research Council
Established by the European Commission

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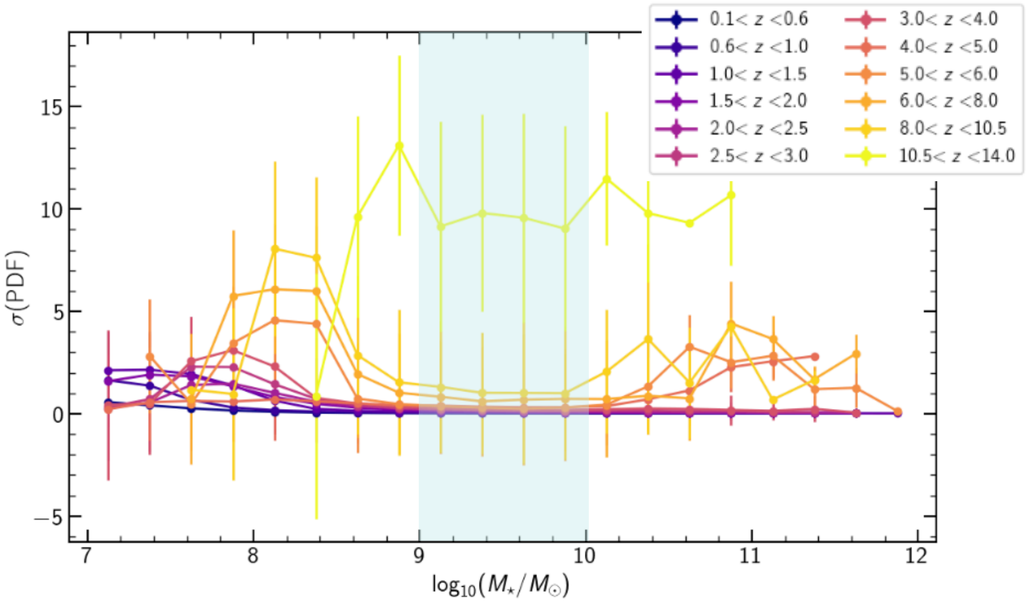
Thank you for your attention!

Appendices

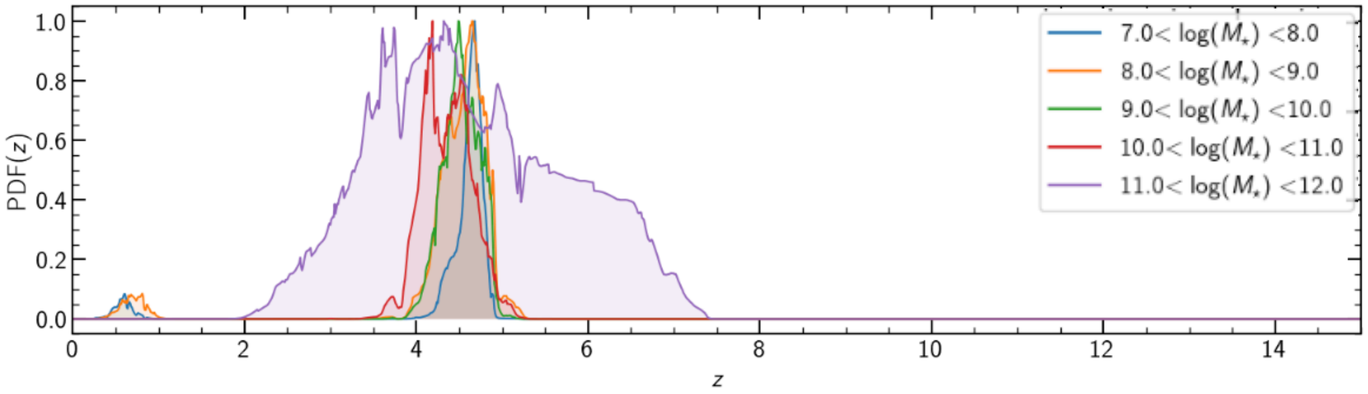
But is it an effect of selection bias?

- Selection bias if PDF(z) selection criteria favors massive galaxies… is it the case?

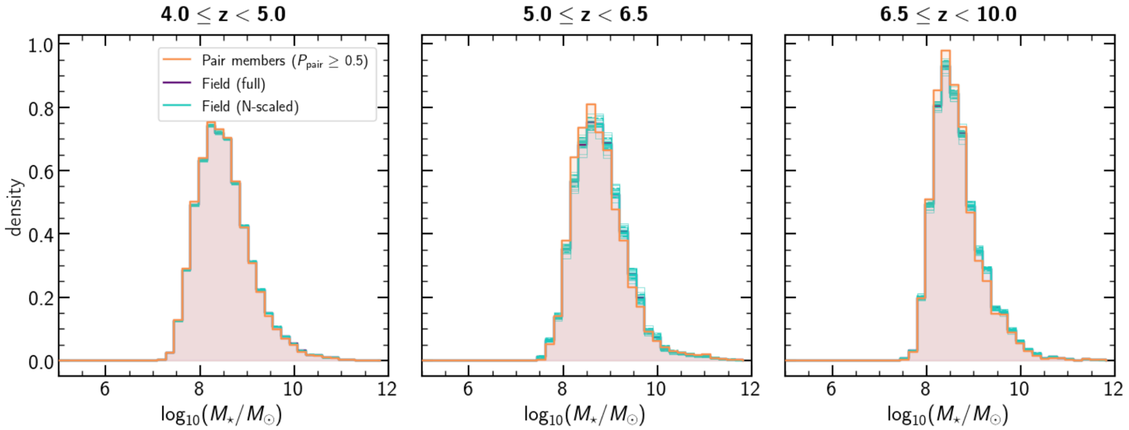
1σ width of PDF(z)



Median PDF(z) in mass ranges at 4 < z < 5



Properties with PDF criteria but $1 < r_{\rm sep} < 2\,{\rm Mpc}$

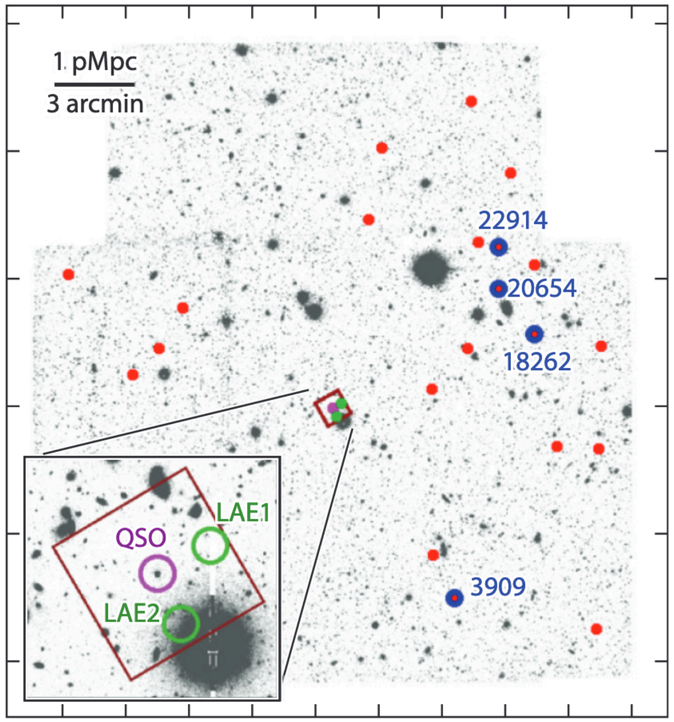


Extreme environments: companions of QSOs

- **QSOs/Quasars** (most-luminous AGNs):
  high SFR, high $M_{\rm BH}$, large gas reservoir, high accretion, strong outflows

- Expected to **trace massive structures**.
  So tracer of the **first regions to be reionized**?
  Tracer of **intense star-formation** regions?
  - Surrounded by large ionized HII regions
  - Overdensities of LBGs, LAEs, [OIII] emitters, … → 50% of QSOs linked to pairs / mergers? Higher interaction/merger rate?

- **Companions** allow to test whether interactions trigger SF/AGN,
  whether they have similar properties with the QSO,
  whether these extreme systems are more efficient at reionizing the CGM/IGM



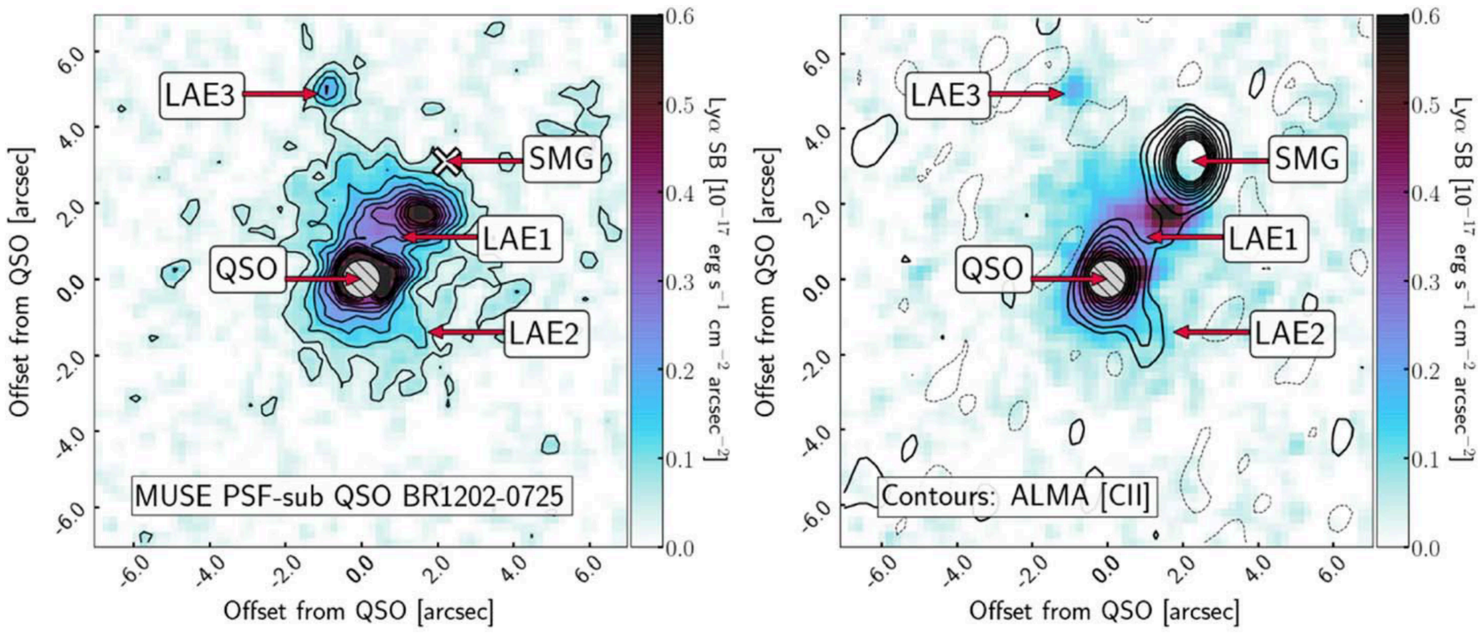
Overdensity around QSO (blue: spec-z confirmed, red: photo-z candidates) [Fan+23]

Extreme environments: companions of QSOs

CASE STUDY:

BR1202-0725 at $z \simeq 4.7$

[e.g., Carilli+13, Drake+20, Zamora+25]



- High obscured SF in QSO
- Very high SFR (> 1000 $M_\odot/\mathrm{yr}$) + signs of AGN in SMG
- Features: >50 kpc Lya halo, [CII] bridge, expanding neutral shell of > 25 kpc

BUT

lack of unified understanding

- Contradictory literature (some QSOs appear isolated, even with deep data)
- Selection biases? Field variance? Wavelengths (FIR vs. UV/opt)?
- Heterogeneous and individual studies

Action 2: Meta-analysis of QSO environments

- From published works and archival observations, what are the environments of QSOs? Which properties have their companion galaxies? Who is dominating the system?
  - Which probes?
  - Detection?
  - Which properties? SFR, $M_\star$, dust, AGN signatures, emission lines, …?
  - Selection? Statistics? Biases?