Unveiling the drivers of LAEs at z>7

Callum Witten

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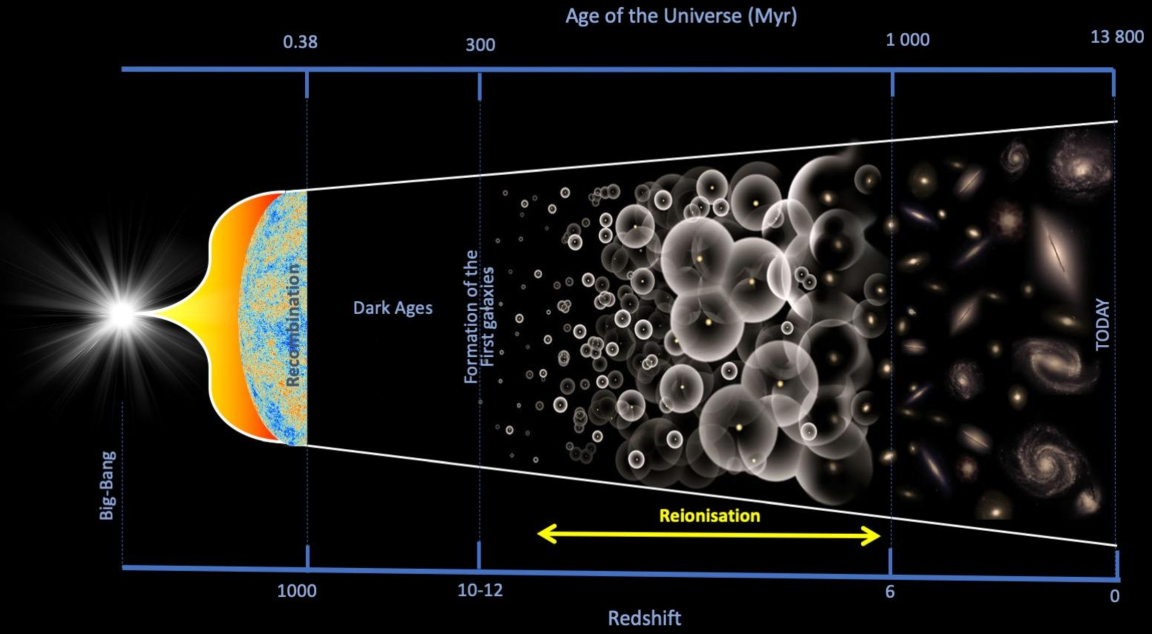
Scientific context



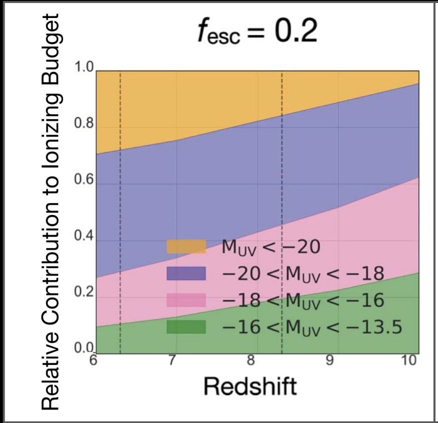
Timeline:

- 380,000 years: Neutral hydrogen forms
- z = 20-15: Formation of the first stars and galaxies (*Cosmic Dawn*) (Bowman et al. 2018, Hashimoto et al. 2018)
- Formation of ionized bubbles
- z = 5-6: Neutral hydrogen is mostly ionized (Robertson et al. 2015, Bosman et al. 2021)

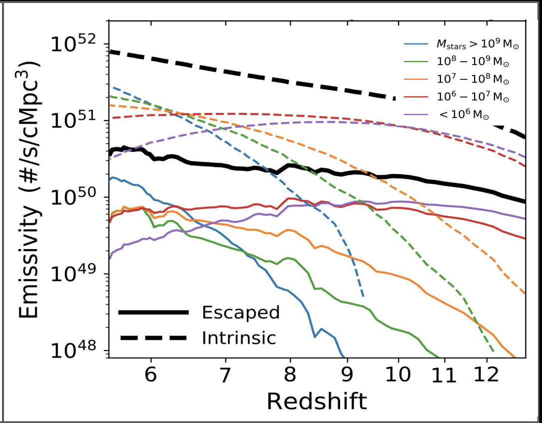
What are the properties of the first generation of galaxies - can they drive reionization?

The creation of the first ionized bubbles

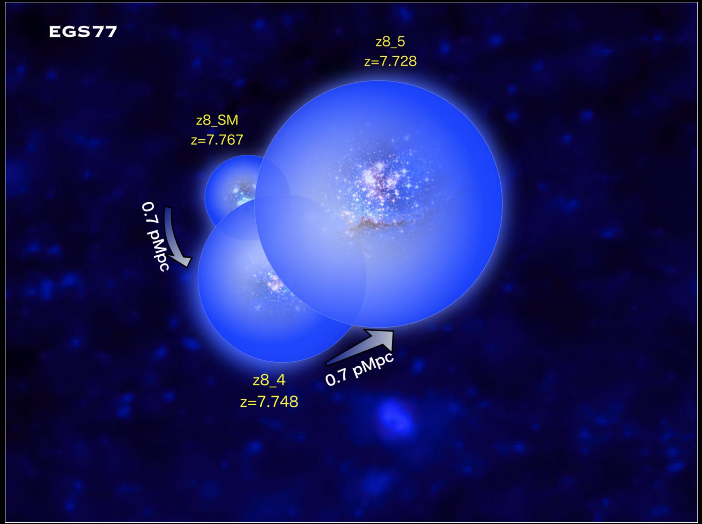
- The formation of ionized bubbles allows for the escape of Ly-α
- What drives the formation of these bubbles: the most massive or least massive galaxies?



Naidu et al. (2020)



Yeh et al. (2022)



Tivli et al. (2020)

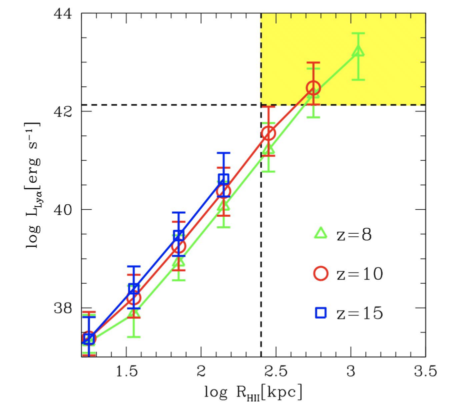
Our understanding of LAEs
pre-JWST

z > 7 LAE sample

Name	z_{syst}	$\log(M_\star)$ $[M_\odot]$	Exposure time	Lyα luminosity $[10^{43}$ erg/s$]$	Telescope	Reference
EGSY-8p68	8.671	$10.1^{+0.1}_{-0.2}$	4 hrs. 45 min.	1.95±0.49	MOSFIRE	Zitrin et al. (2015)
EGS-zs8-1	7.721	$10.2^{+0.2}_{-0.1}$	4 hrs.	1.2±0.1	MOSFIRE	Tilvi et al. (2020)
			4 hrs.	1.2±0.2	MOSFIRE	Oesch et al. (2015)
COSY	7.142	$10.2^{+0.1}_{-0.8}$	12 hrs.	1.43±0.19	X-Shooter	Laporte et al. (2017)

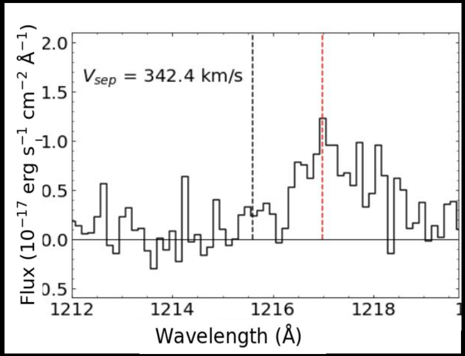
Our sample is heavily biased towards the most luminous and massive high redshifts galaxies.

Based on models from Yajima et al. (2018) we expect each of these galaxies to reside in ionized bubbles with radius ~ 1 Mpc.

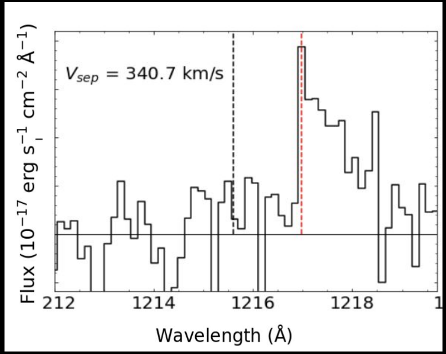


Yajima et al. (2018)

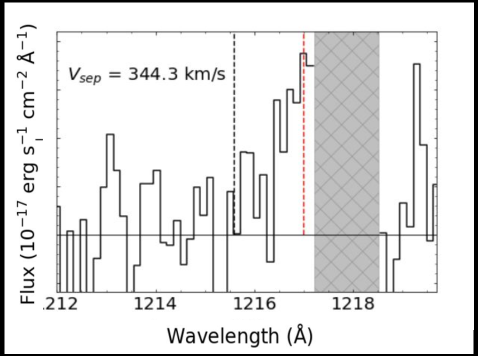
A Ly-α stack of z > 7 galaxies



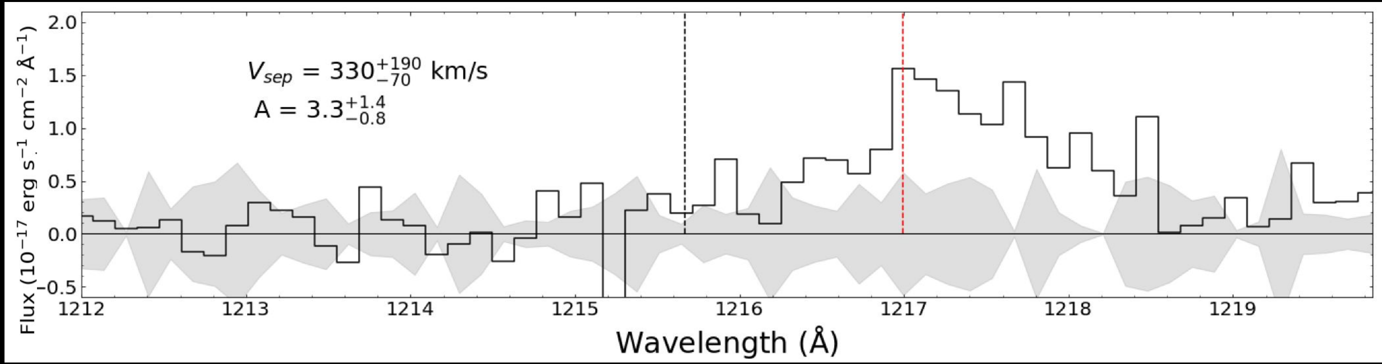
EGS-zs8-1



EGSY-8p68

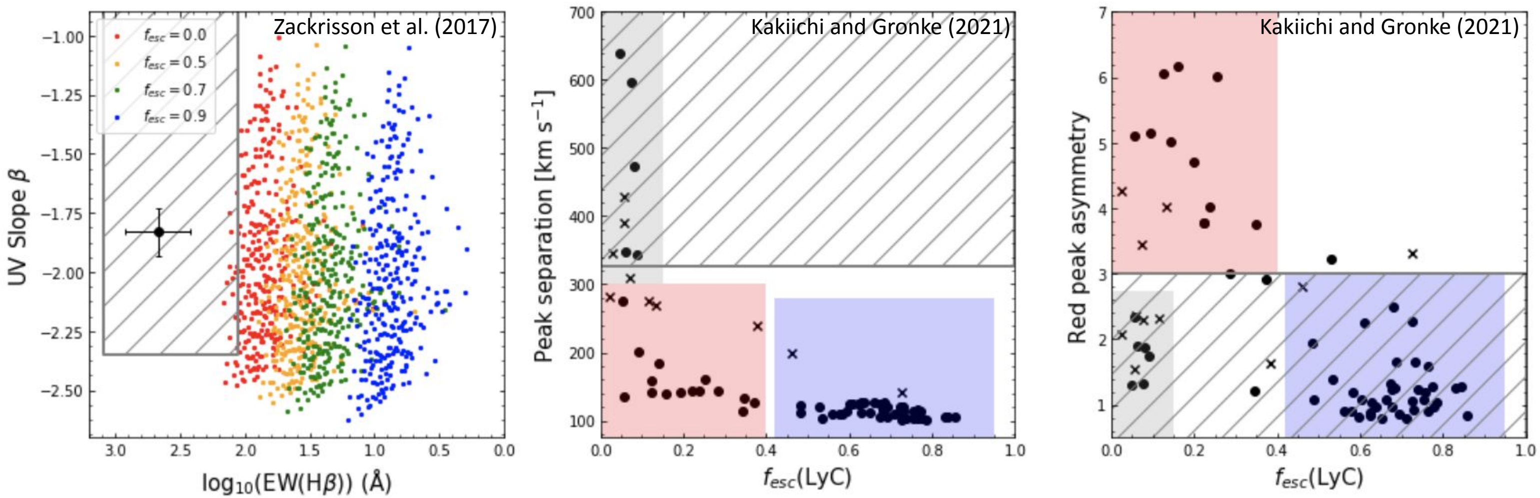


COSY



Witten et al. (2023a)

A Ly-α stack of z > 7 galaxies



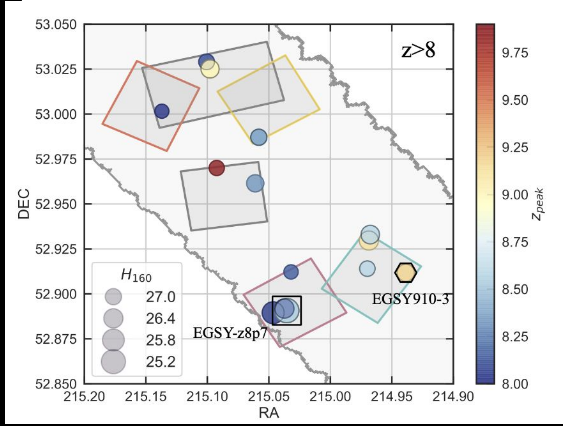
Diagnostic	Value	f_{esc}
Spitzer: flux (Hβ + [OIII])	7.13×10^{-17}erg/s/cm^2/Å	[0.02, 0.16]
BAGPIPES: flux (Hβ)	$1.1^{+0.9}_{-0.5} \times 10^{-17}$erg/s/cm^2/Å	$0.09^{+0.07}_{-0.04}$
Spitzer: UV slope β and $\log_{10}$(EW(Hβ + [OIII]))	[-0.6, -2.35], [2.0 Å, 3.1 Å]	~ 0
BAGPIPES: UV slope β and $\log_{10}$(EW(Hβ))	$-1.89^{+0.09}_{-0.11}$, 2.67 ± 0.25	~ 0
Lyα profile: Asymmetry and Peak separation	$A = 3$, $V_{\mathrm{redpeak}} = 327$ km/s	< 0.15

Witten et al. 2023a

So what does drive reionization?

A hard-ionization field – single object

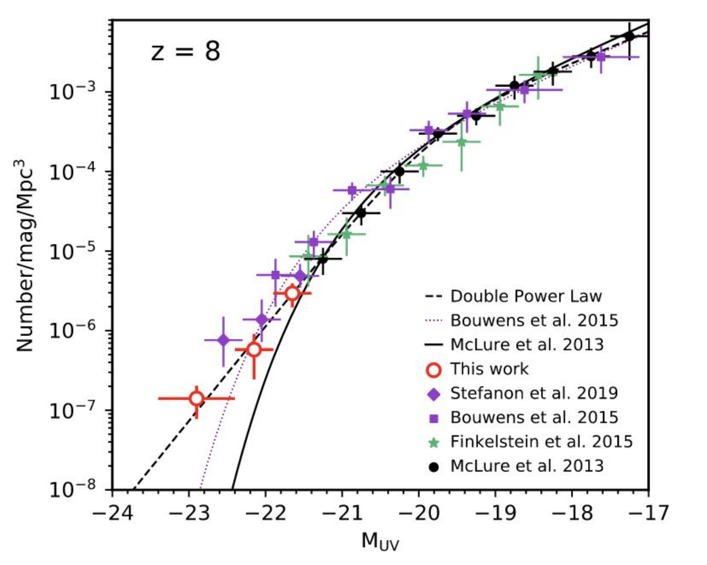
- Observations of the brightest sources at z>7 with UltraVISTA suggest that AGN Feedback is not present yet (Bowler et al. 2014, 2021)
- Some examples of AGN up to z=8.68 have been found recently with the detection of high ionising potential emission lines (Mainali et al. 2018, Laporte et al. 2017)



Leonova et al. (2022)

An enhanced radiation field – multiple objects

- An overdensity of galaxies has been identified around one of the AGN candidates at z=8.68
- This suggests that even if these objects are rare, they may have played a crucial role in the reionisation of the Universe

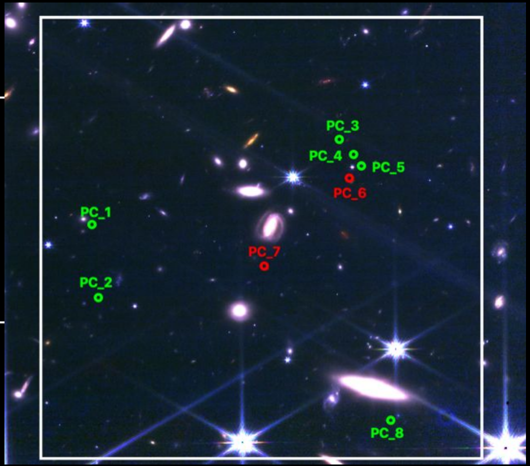


Bowler et al. (2020)

Our understanding of LAEs since the advent of *JWST*

Protoclusters?

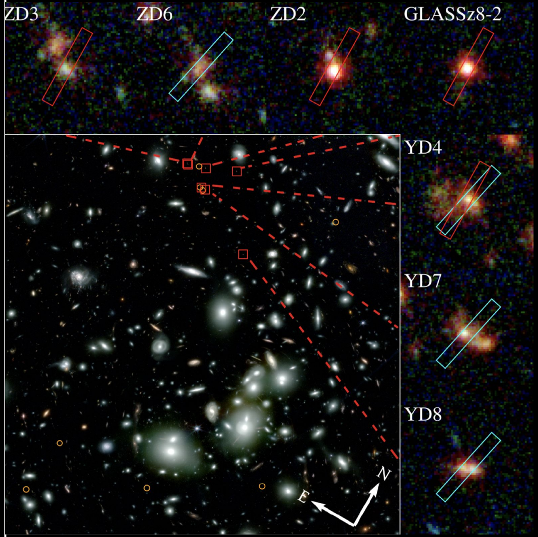
- Immediate identification of two galaxies at same redshift in early-release SMACS0723 JWST/NIRSpec data (Curti et al. 2022)
- Followed by the identification of multiple photometric candidates (Laporte,**CW** et al. 2022)



Laporte,**CW** et al. (2022)

And more…

- A spectroscopically confirmed protocluster at z = 7.88 (Morishita et al. 2023)
- An overdensity of z=10 candidates in the lensed Abell2744 field (Castellano et al. 2023)
- A photometric overdensity of bright OIII emitters around a LAE at z~7 (Witten et al. 2023c in prep.)
- Overdensity around GN-z11 (Tacchella et al. 2023), z~7.3 overdensity (Saxena et al. 2023), EGS overdensities (eg. Jung et al. 2023)...



Morishita et al. (2023)

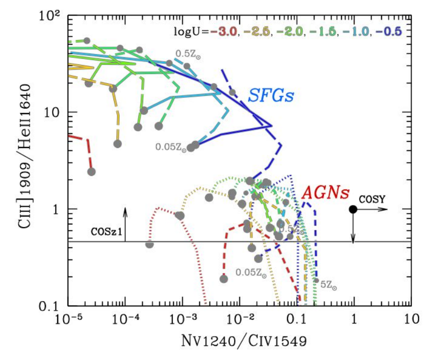
Examples of numerous ionized bubbles around overdensities, eg. Leonova et al. (2022), Jung et al. (2022), Tang et al. (2023)

AGNs?

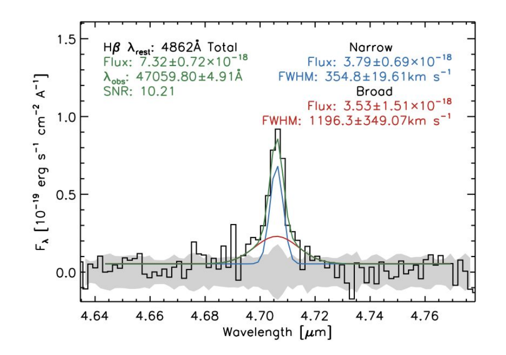
Interpretation of the abundance of protocluster is further complicated by the presence of several AGN within them

Detection of broad emission potentially originating from the broad-line region in Larson et al. (2023)

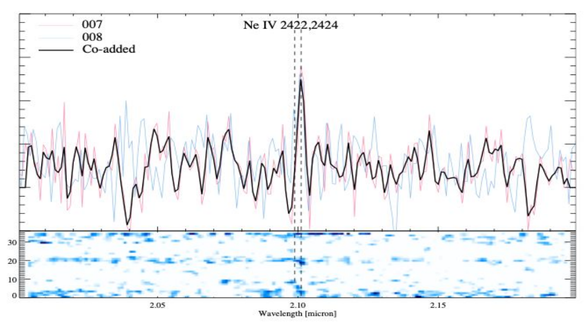
Laporte et al. (2017)



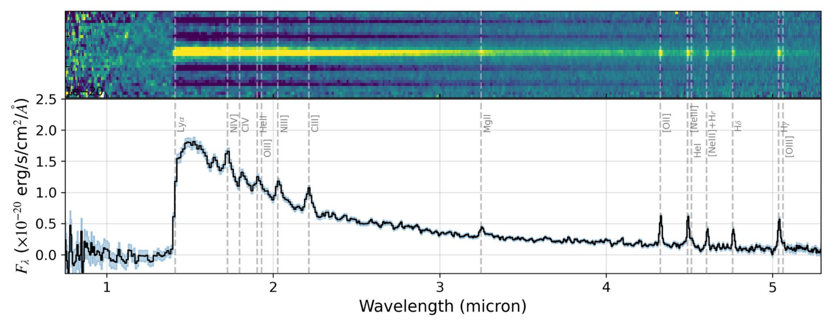
- The presence of NeIV and line ratios suggests the SMACS0723 protocluster hosts an AGN (Brinchmann 2022)
- Presence of NIV in GN-z11 is indicative of strong ionization field
- The candidate protocluster at z ~ 7 is surrounding a LAE that is a candidate AGN (Laporte et al. 2017)



Larson et al. (2023)



Brinchmann (2022)



Bunker et al. (2023)

What drives Ly-α emission in these galaxies?

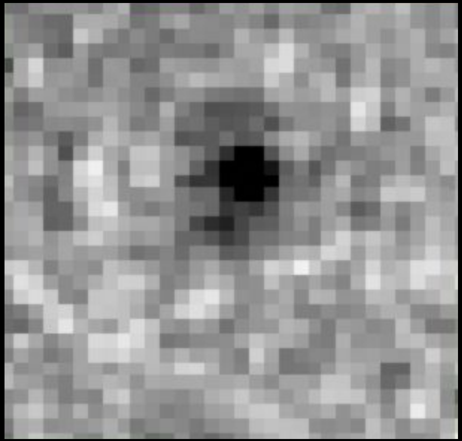
We take all z > 7 LAEs that have existing, publicly-available NIRCam imaging and use this improvement over HST to place stronger constraints on galaxy properties such as stellar mass, SFR and morphology

ID	z	$\log(M_*[M_\odot])$	SFR $[M_\odot/yr]$	$EW(Ly\alpha)[\AA]$	$f_{esc}(Ly\alpha)$
COSY	7.142	$8.77^{+0.02}_{-0.02}$	$5.91^{+0.27}_{-0.25}$	27.5	< 0.1
z7-GSD-3811	7.661	$8.96^{+0.12}_{-0.13}$	$9.25^{+2.79}_{-2.39}$	15.6	0.22 ± 0.08
EGSY-8p68	8.683	$8.88^{+0.10}_{-0.18}$	$7.62^{+1.87}_{-2.54}$	10.7	< 0.1
CEERS-44	7.10	$7.59^{+0.06}_{-0.06}$	$0.39^{+0.06}_{-0.05}$	77.6	0.339 ± 0.044
CEERS-1027	7.819	$7.94^{+0.05}_{-0.04}$	$0.87^{+0.10}_{-0.08}$	20.4	0.085 ± 0.018
z7-13433	7.482	$9.62^{+0.01}_{-0.01}$	$42.19^{+1.09}_{-1.00}$	22.2	–
z7-20237	7.623	$9.25^{+0.12}_{-0.15}$	$8.86^{+2.04}_{-1.63}$	17.1	–
GSDY	7.957	$9.42^{+0.21}_{-0.27}$	$17.80^{+4.56}_{-5.02}$	17.6	> 0.11

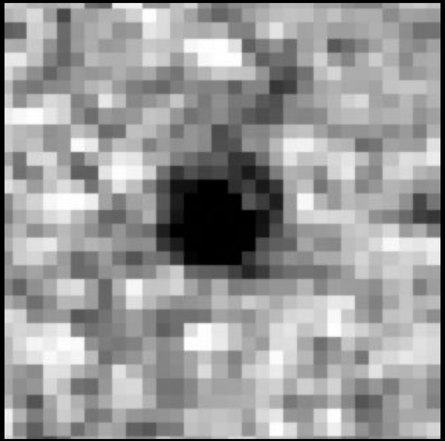
Most of these galaxies reside within known ionized bubbles explaining the observation of Ly-α

Morphology

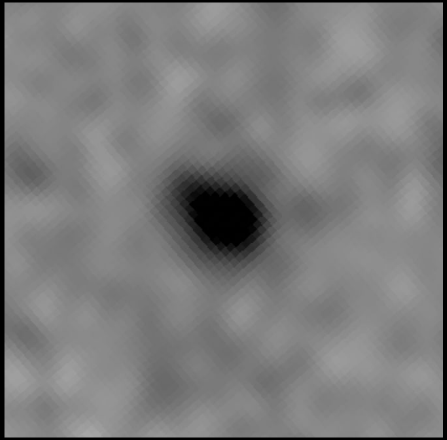
Can NIRCam's improved resolution and sensitivity reveal anything noteworthy?



z7-GSD-3811



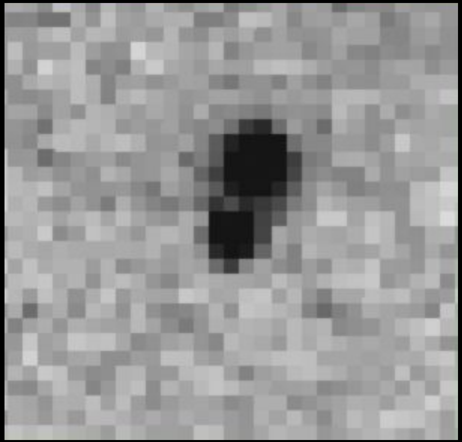
COSY



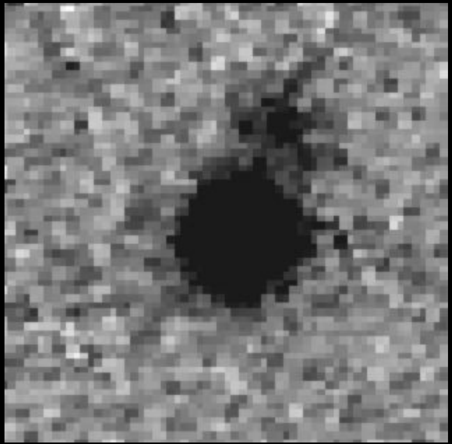
EGSY-8p68

Morphology

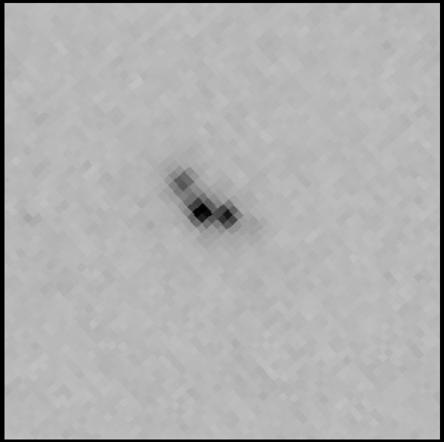
Can NIRCam's improved resolution and sensitivity reveal anything noteworthy? YES!



z7-GSD-3811

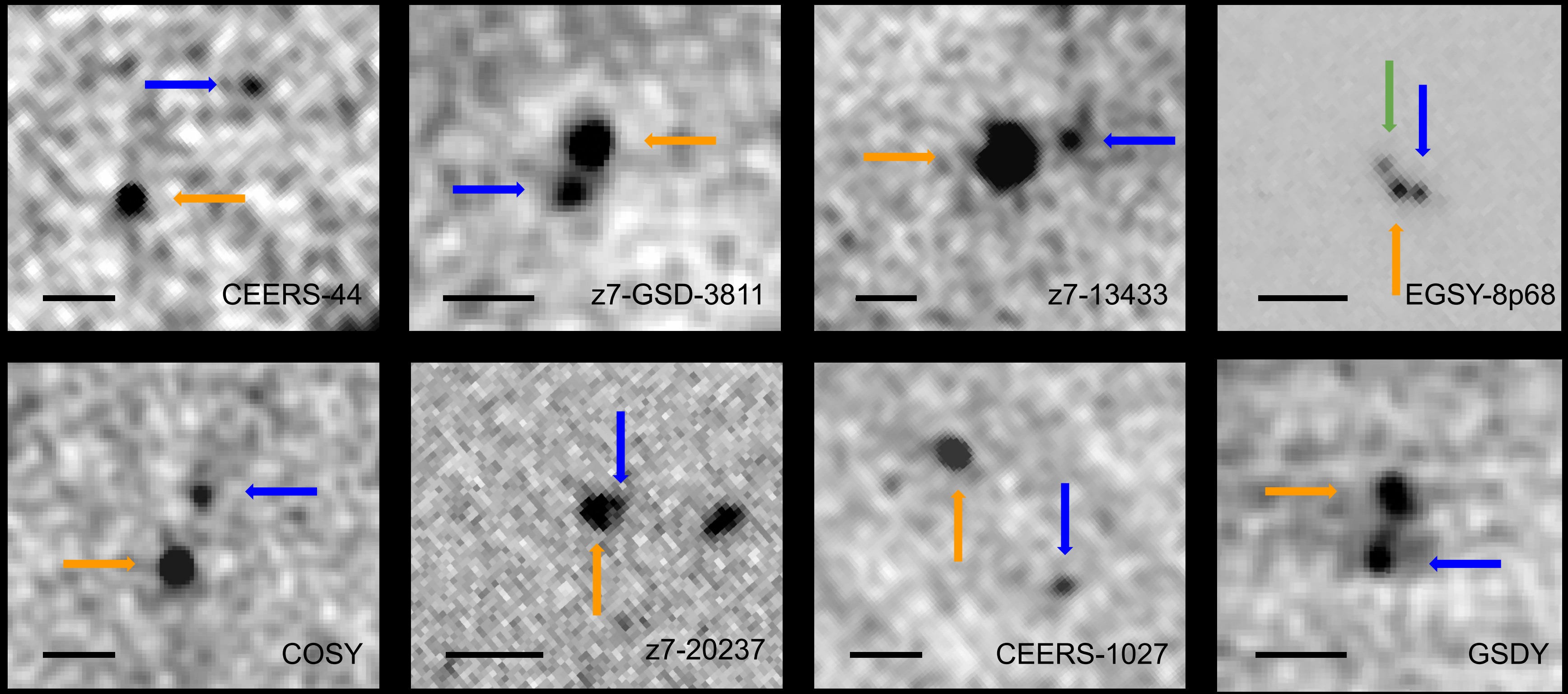


COSY



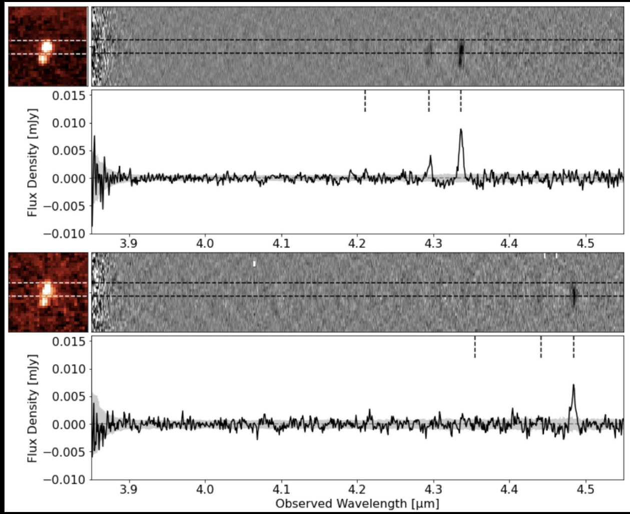
EGSY-8p68

Close companions in 100% of our sample

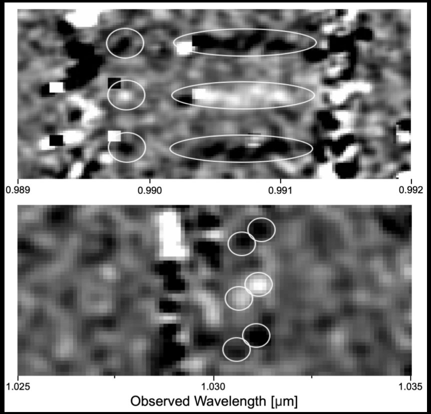


Witten et al. (2023b Submitted)

Confirmation of companions at z > 7



- Spectroscopic confirmation of two systems with strong OIII and two with tentative confirmation of Ly-α
- Strong photometric constraints on the remaining four systems lead us to conclude these are indeed objects at the same redshift
- Furthermore, we obtain constraints on H**β** allowing us to confirm the escape fraction of Ly-α and to confirm their high SFR_{inst}

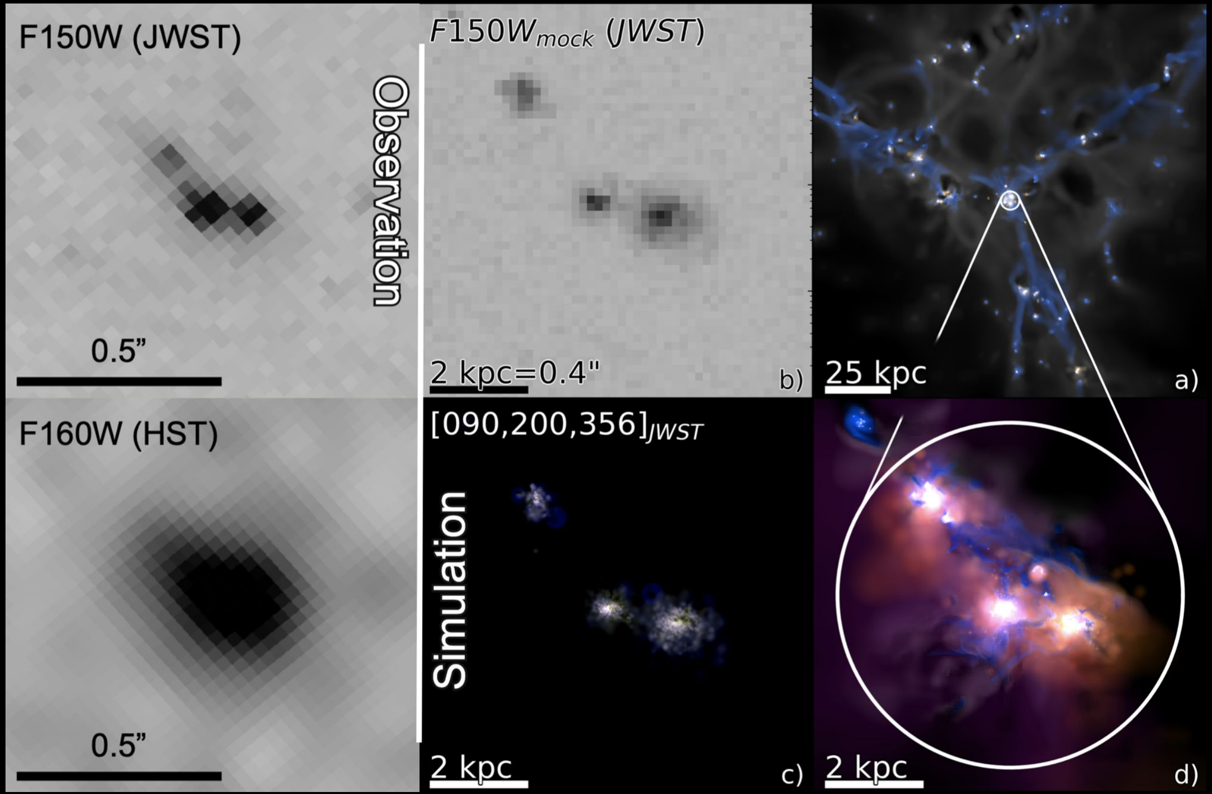


ID	z	$[OIII]_{5007}$	$[OIII]_{4959}$	$H\beta$	$SFR_{inst}[M_\odot/yr]$
z7-GSD-3811-A	7.663	8.3 ± 0.4	2.7 ± 0.4	1.0 ± 0.3	16.5 ± 4.9
z7-GSD-3811-B	7.658	4.8 ± 0.4	1.5 ± 0.3	< 0.5	< 8.2
GSDY-A	7.956	5.8 ± 0.7	1.0 ± 0.4	< 0.5	< 9.0
GSDY-B	7.957	3.1 ± 0.6	1.5 ± 0.6	0.8 ± 0.3	14.4 ± 5.4

Flux in 10^{-18} erg/s/cm^2

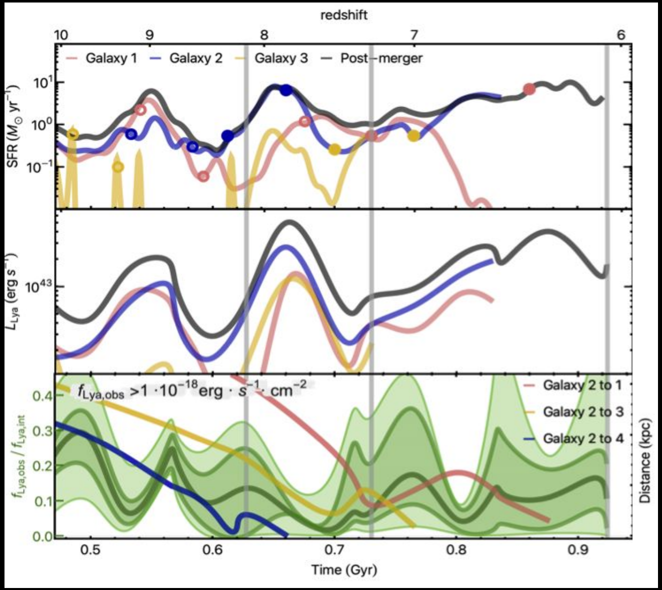
Witten et al. (2023b Submitted)

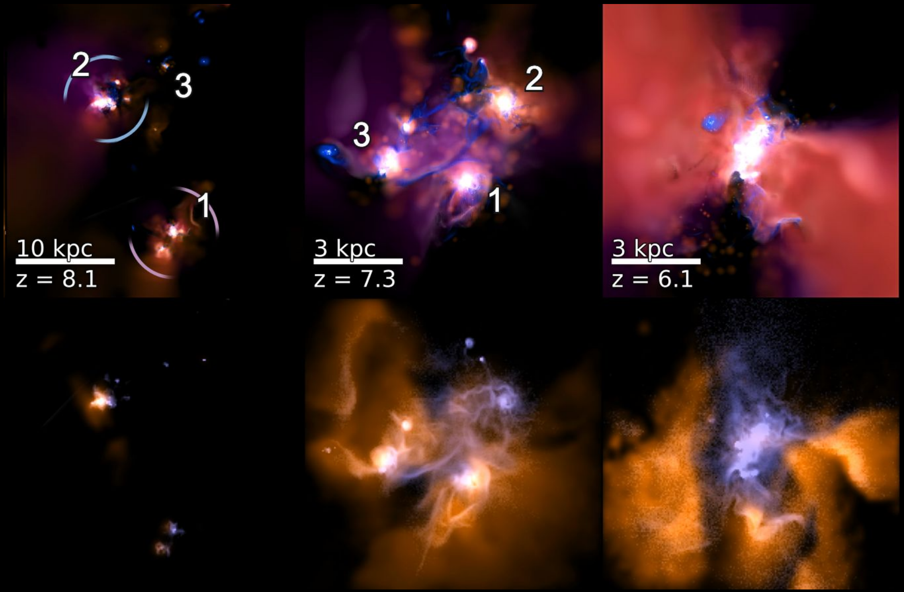
Azahar suite simulations



Cosmological zoom-in simulations of high-redshift galaxies, which self-consistently model on-the-fly radiative transfer, magnetic fields and cosmic ray feedback (Martin Alvarez et al. 2023 in prep.)

Mergers driving Ly-α emission in z > 7 galaxies





HI density

F150W intensit
y

LyC ion. rad.

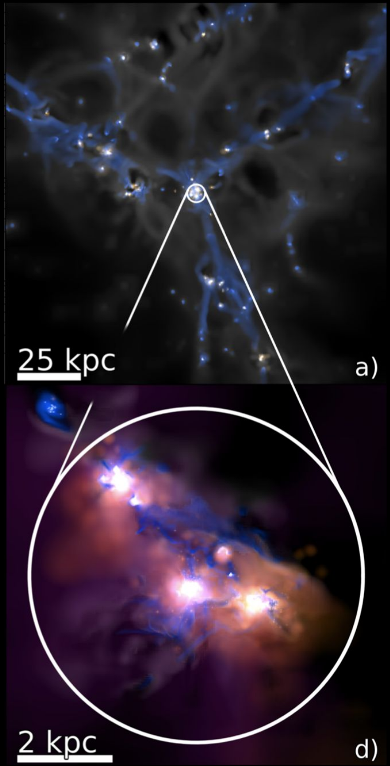
HeII ion. rad.

Ly-α intrinsic

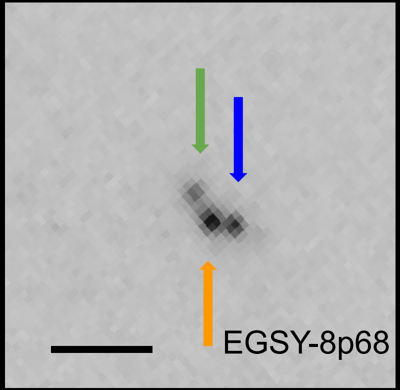
Ly-α scattered

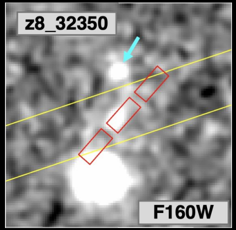
Witten et al. (2023b Submitted)

The ingredients to make an LAE at z > 7

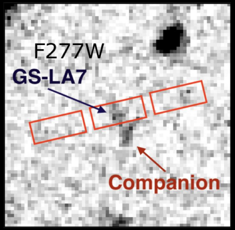


1. Interactions and mergers driving episodic star-formation that in turn drives intrinsic Ly-α emission
2. A 'favourable' line-of-sight cleared of neutral hydrogen in the host galaxy by tidal interactions with companions and by star-formation feedback
3. Resident within a sufficiently large ionised bubble facilitating the escape of Ly-α emission through the IGM, likely driven by an overdensity

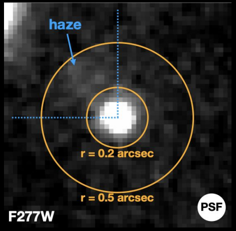




Jung et al. (2023)

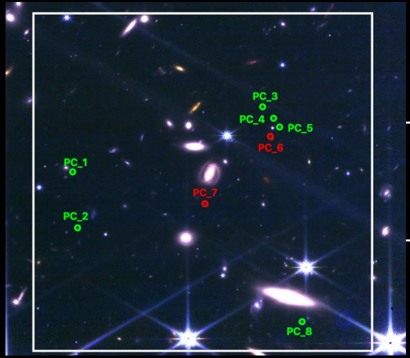


Saxena et al. (2023)



Tacchella et al. (2023)

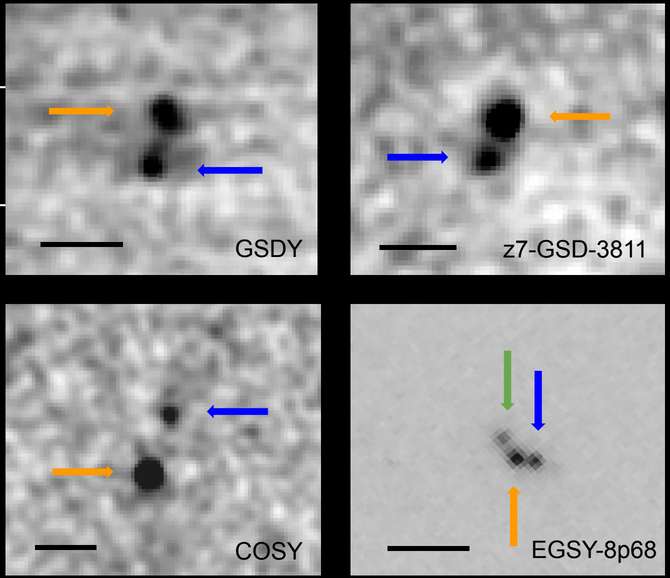
Conclusions



Laporte,**CW** et al. (2022)

Overdensities appear common at high-z, but the presence of AGN within many of them complicate conclusions on their importance for reionization

New NIRCam observations indicate LAEs at z > 7 have close companions



New simulations show mergers drive a boost in SF and a clearing of neutral hydrogen around the merging galaxies likely facilitating the escape of Lya photons