High Ly-α visibility from a reionized overdensity at z~7

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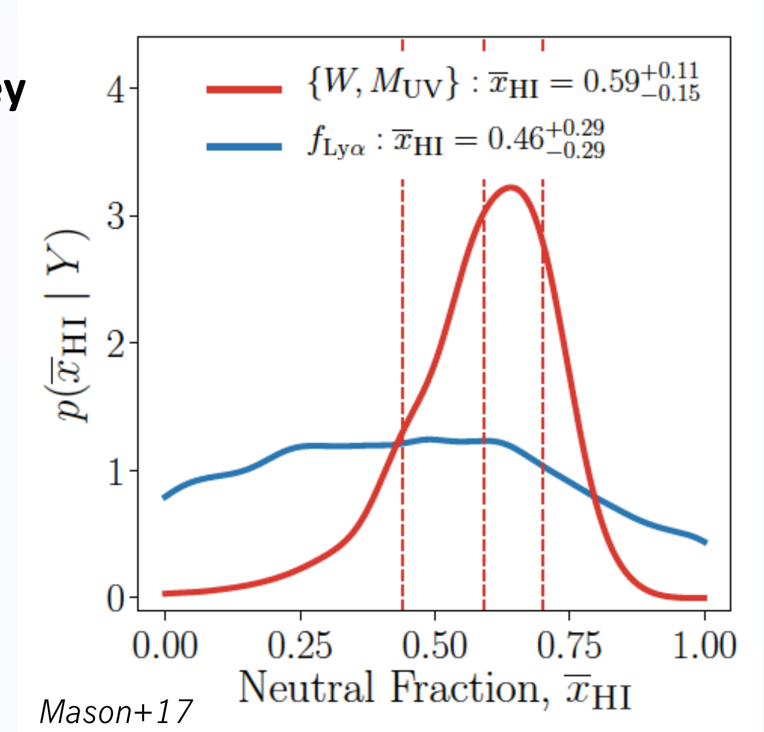
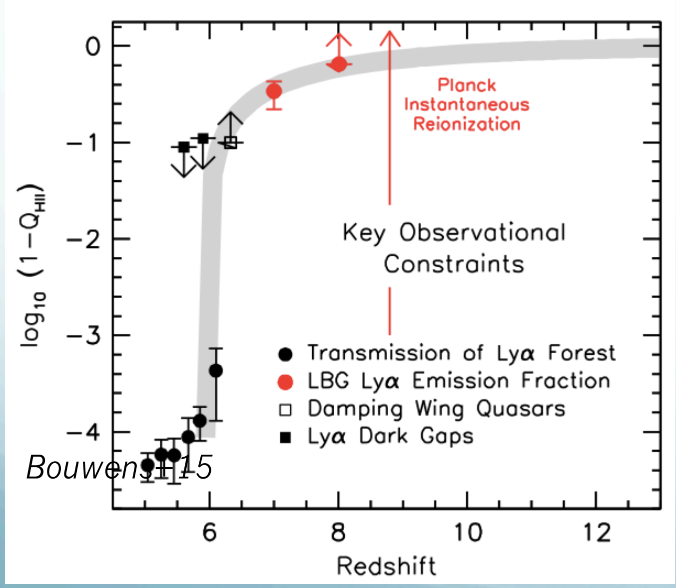
OAR

Timeline and sources of HI Reionization

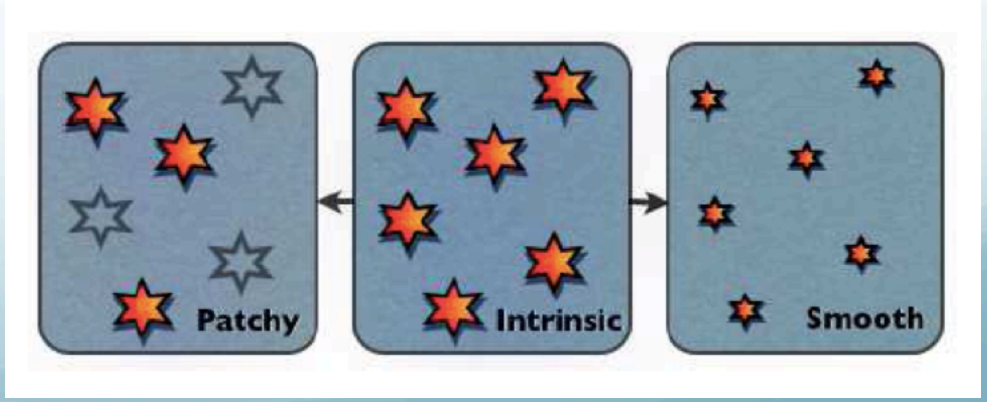
***Decline of Lyα visibility in star-forming galaxies key probe of late reionization** (e.g. Stark+10, Fontana+10, Pentericci+11,+14, Schenker+12)

***Reionization timeline can be explained by the evolution of UV luminosity density** from star-forming galaxies (e.g. Bouwens+15, Robertson+15).





Patchy topology favoured (Treu+12, Pentericci+14)

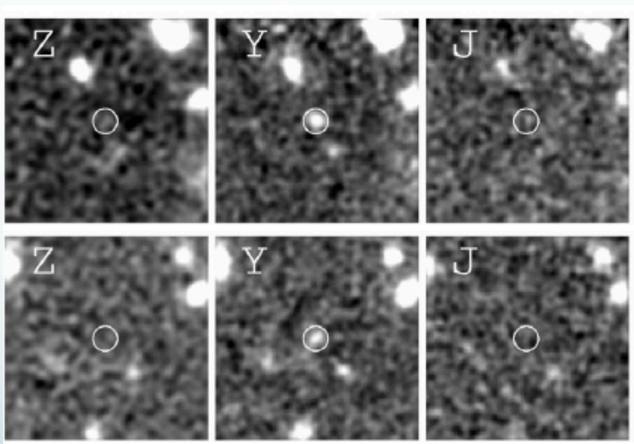


A space oddity at z=7: two close-by strong LAEs

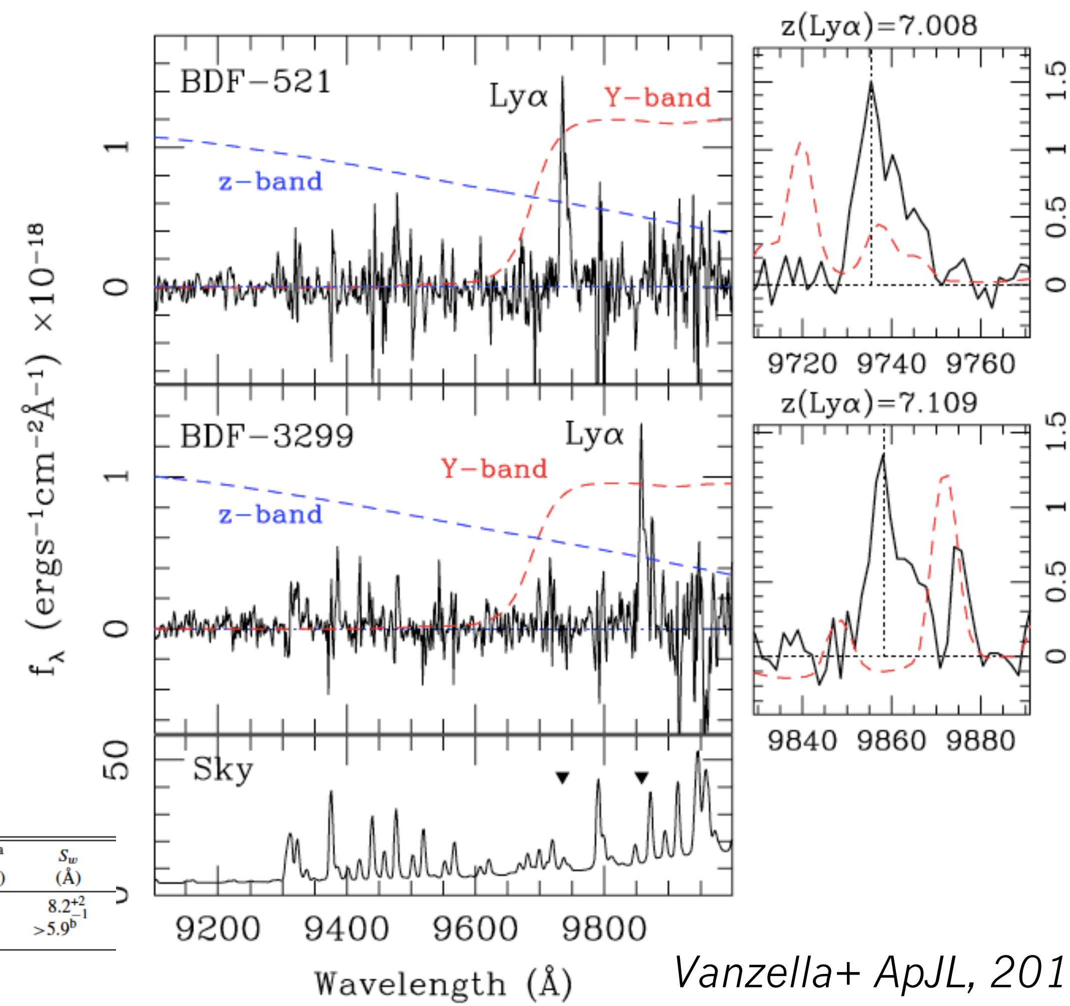
In the overall paucity of Lyα lines: one line of sight with twin bright emitters among the 8 l.o.s. investigated in Pentericci+14.

The BDF4 field (Lehnert&Bremer 03) hosts two close-by (1.9 pMpc projected distance) EW~50-60AA emitters. Their L_{UV} cannot build a large enough HII region to explain line visibility (Vanzella+11).

Additional sources required?
(e.g. Dayal+09)



MC+ A&A, 2010b

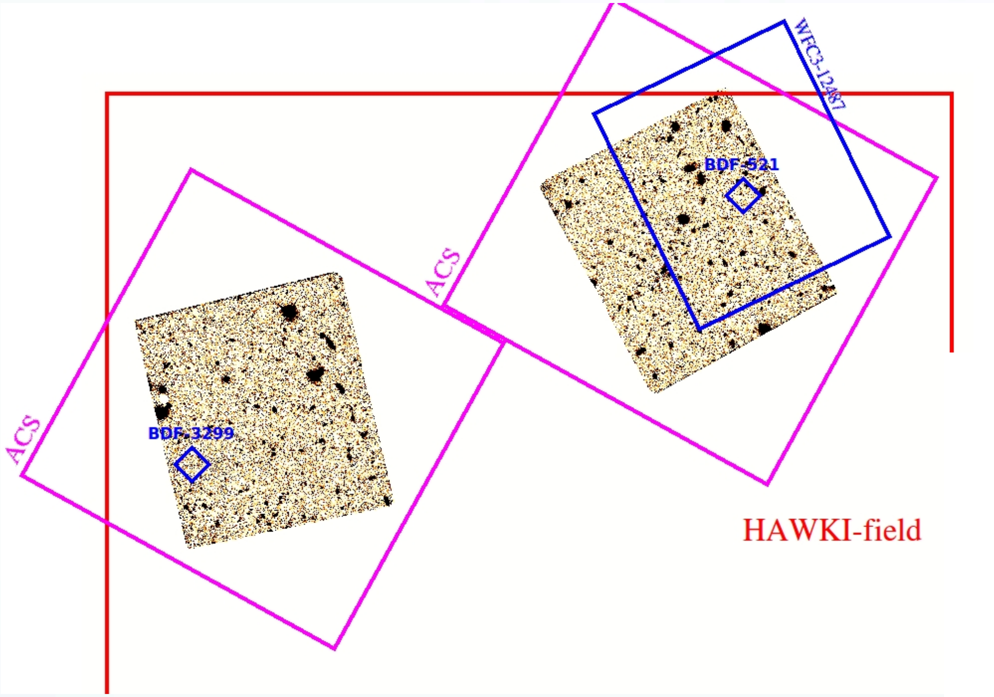


Vanzella+ ApJL, 2011

ID	R.A., Decl. J2000	Redshift	f(Lyα)	SFR(Lyα) ($M_\odot$ yr^{-1})	EW$_{rest}$ (Å)	FWHM[a] (km s^{-1})	S_w (Å)
BDF−521	336.9444, −35.1188	7.008 ± 0.002	1.62 ± 0.16	8.5	64	240	8.2^{+2}_{-1}
BDF−3299	337.0511, −35.1665	7.109 ± 0.002	1.21 ± 0.14	6.6	50	200	>5.9[b]

Notes. f(Lyα) in units of 10^{-17} erg s^{-1} cm^{-2} Å^{-1}.

A closer look at the BDF region with HST



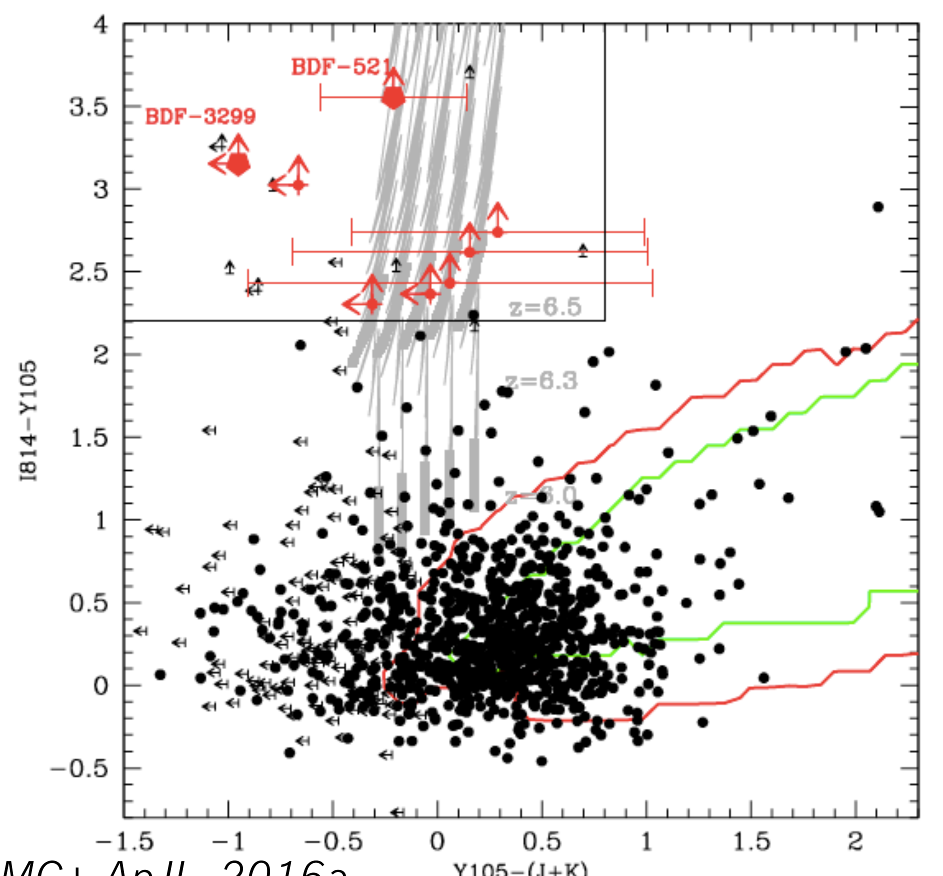
HST Cycle 22 program (PI MC) to look for surrounding, fainter LBGs.

14 orbits with V606, I814, Y105.

Previous Hawk-I data limited to Y~26.5.

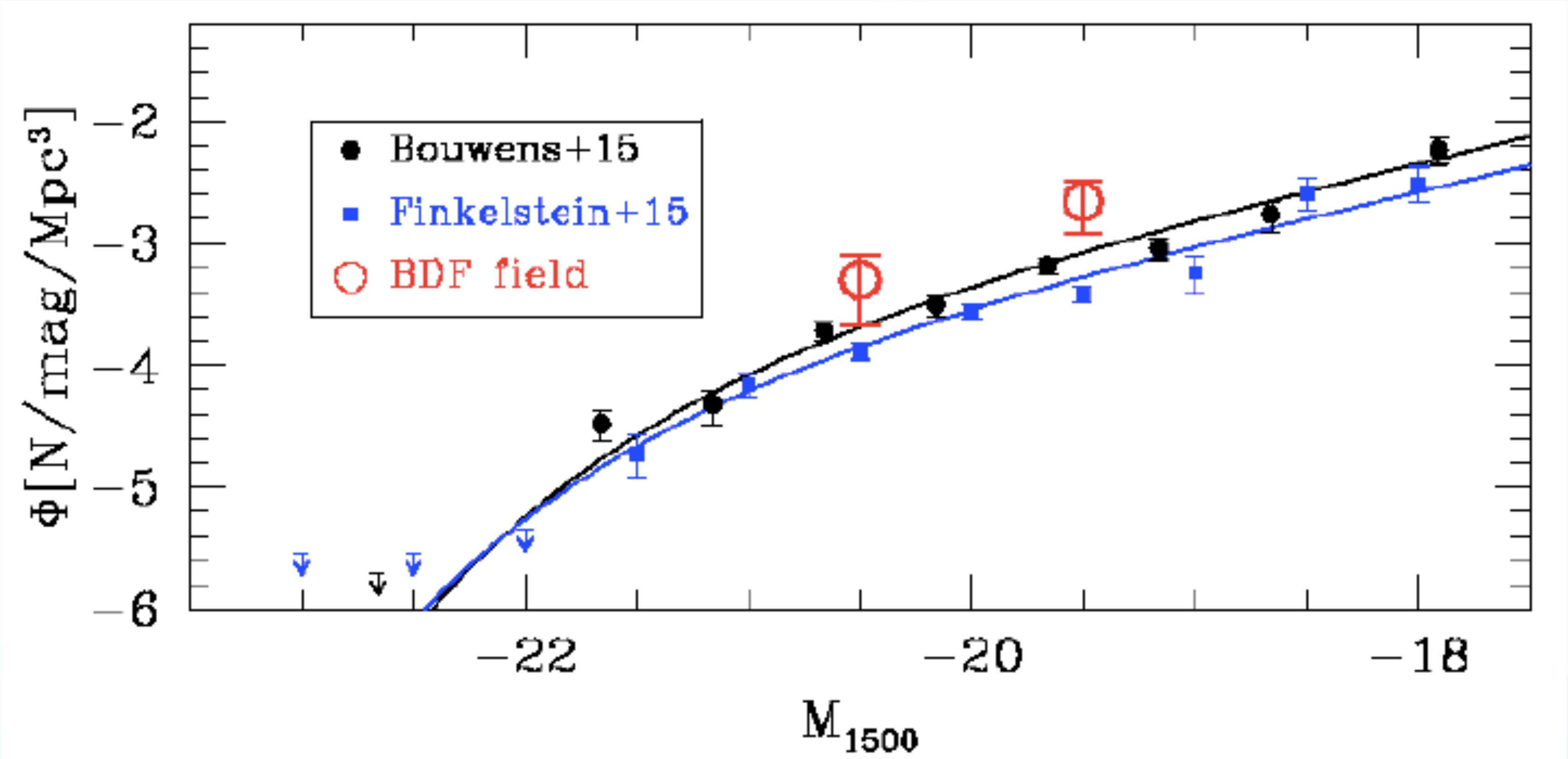
Six robust LBGs recovered at Y105~26.5-27.5 (S/N>10)

$$(S/N(I_{814}) < 1) \wedge (I_{814} - Y_{105} > 2.2)$$
$$Y_{105} - (J+K) < 0.8$$
$$(S/N(Y_{105}) > 10) \wedge (S/N(V_{606})) < 1,$$



MC+ ApJL, 2016a

An overdensity of LBGs at z~7

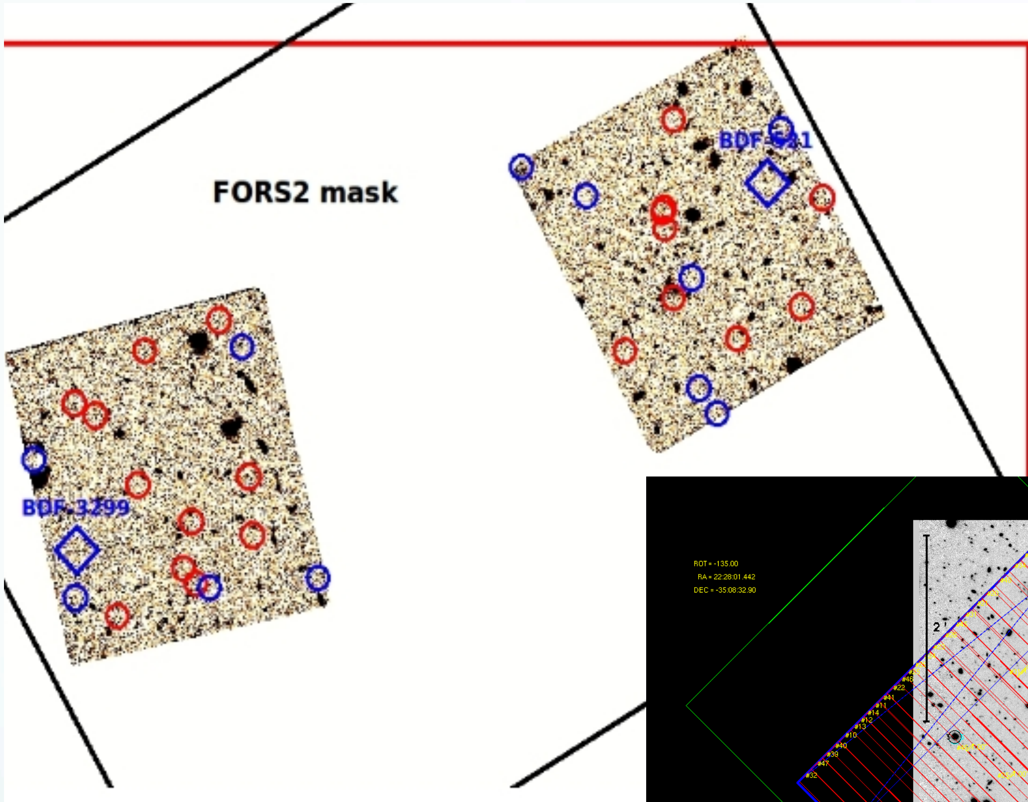


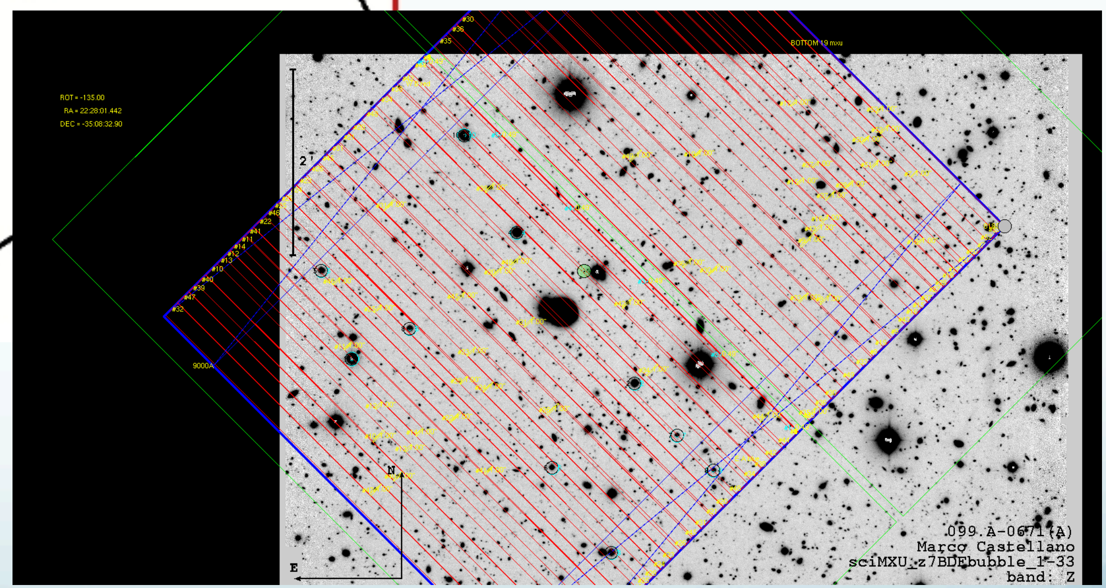
Observed= 8 objects in two pointings. Expected ~1.8-2.9 objects.

The BDF field is 3-4x overdense wrt average: consistent with a positive relation between line visibility and galaxy density as in ***inside-out reionization scenarios.*** (e.g. McQuinn+ 07, Wyithe&Loeb 07, Dayal+ 09). *No similar clustering around bright z~7 LBGs in CANDELS GS.*

MC+ ApJL, 2016a

Spectroscopic follow-up



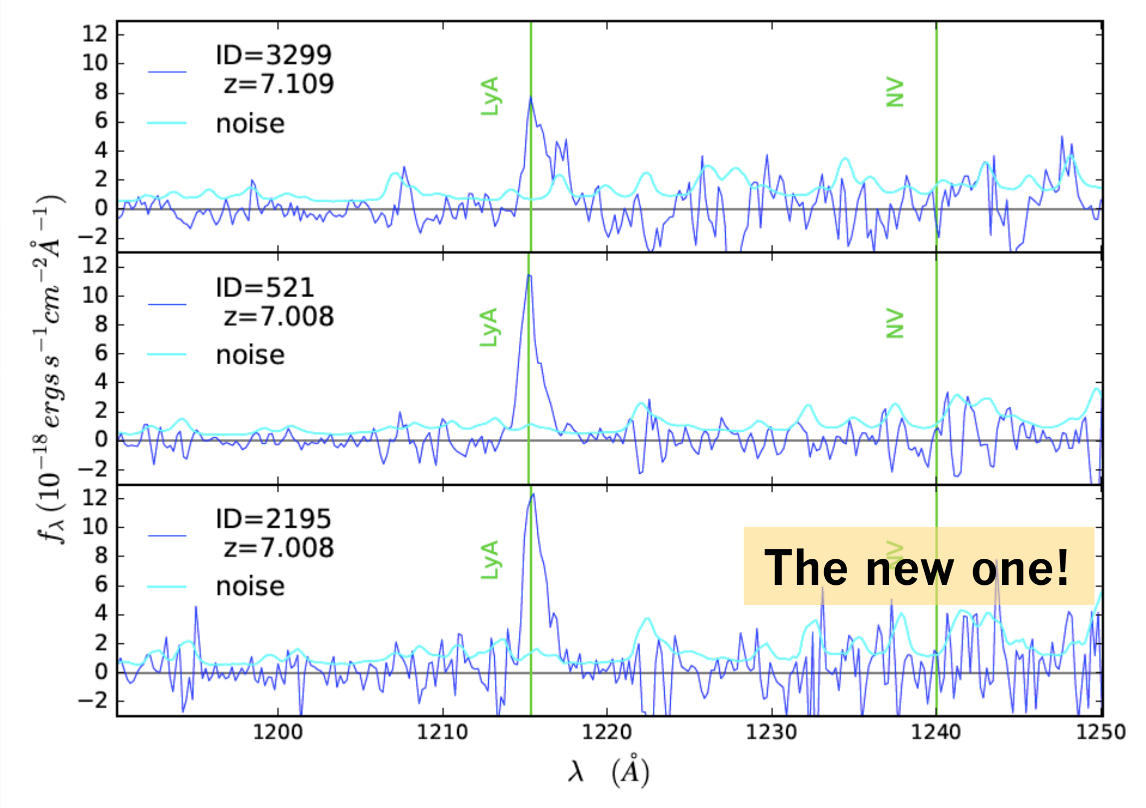


33 hrs FORS2@VLT, (program 099.A-0671 P.I. MC)

600z+23(OG590) grism (resolution R=1390), with slits 1” wide and a length in the range 6-12”

Observed 14 robust S/N(Y105)>5 z~7 candidates, plus z~6 fillers and lower quality LBGs

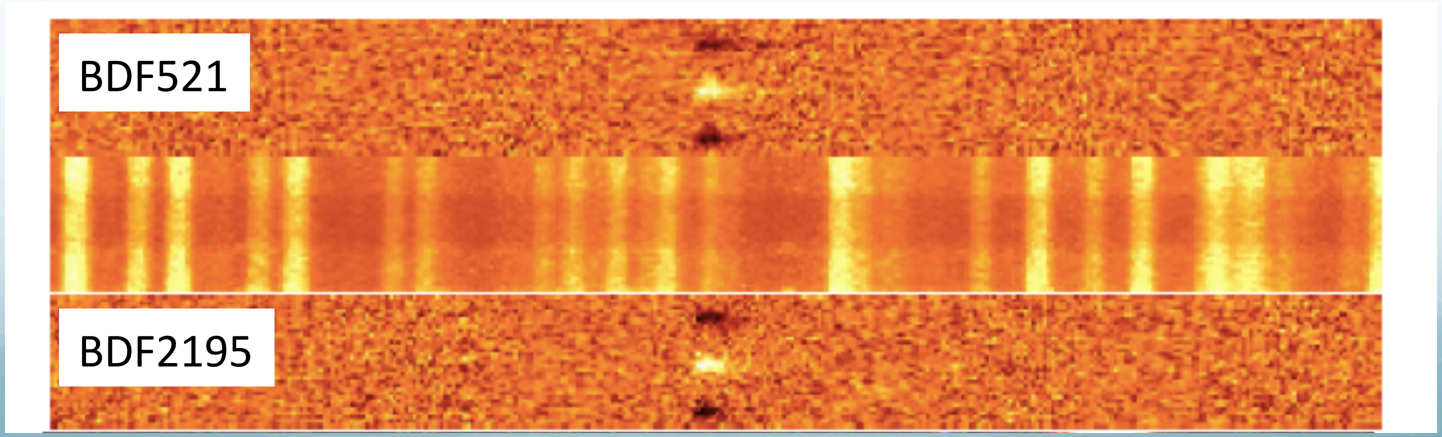
A third bright emitter at the same redshift



Z=7.109
EW=50AA
FWHM=200 km/s

Z=7.008
EW=64AA
FWHM=240 km/s

Z=7.008
EW=50AA
FWHM=240 km/s



MC+ ApJL, 2018

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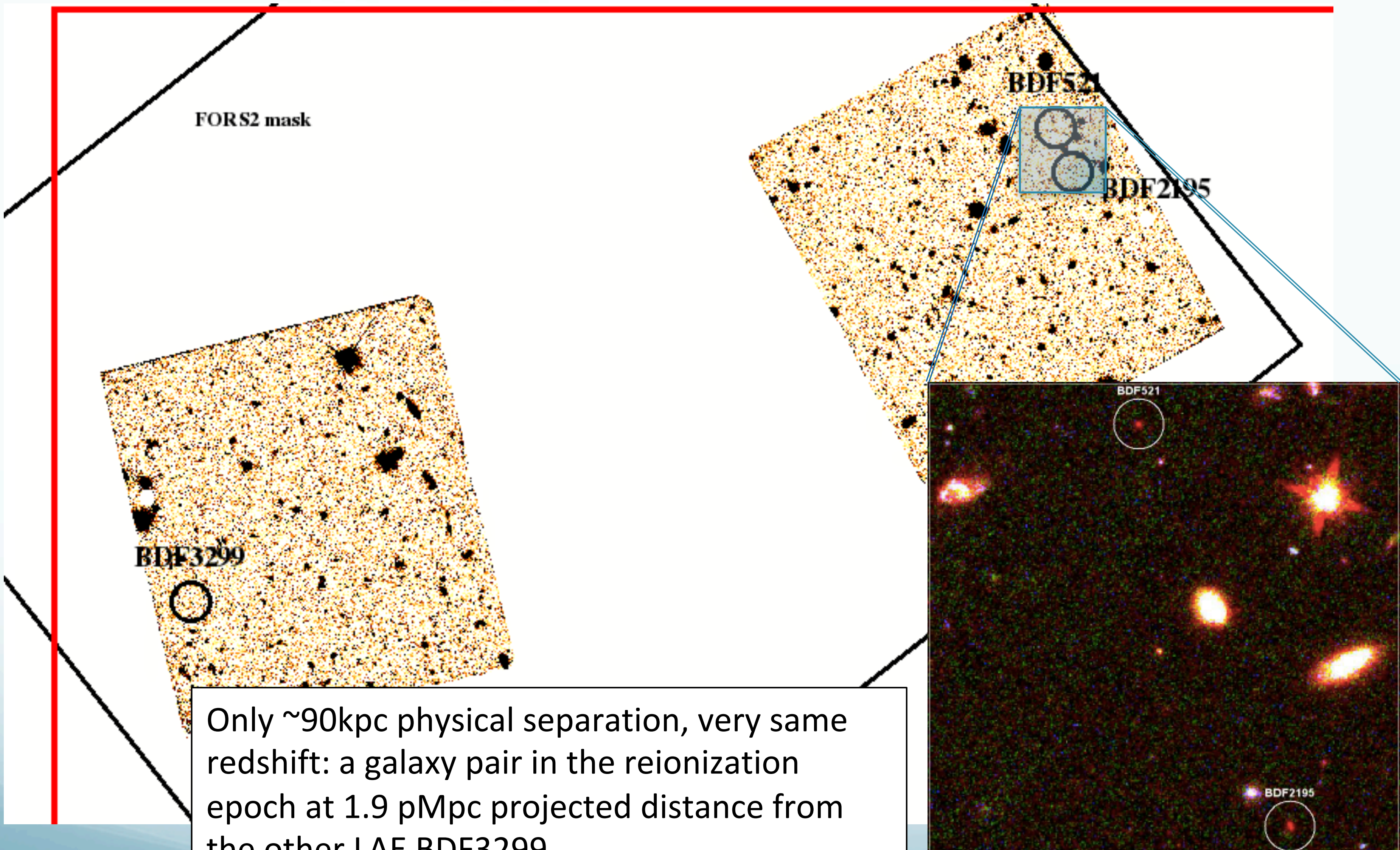


Only ~90kpc physical separation, very same redshift: a galaxy pair in the reionization epoch at 1.9 pMpc projected distance from the other LAE BDF3299

MC+ ApJL, 2018

No Lyα from any of the faint galaxies

Sample	Total	Bright	Faint
Observed	17	5	12
Detected in Lyα	3	3	0

3 out of 5 "bright" LBGs have Lyα

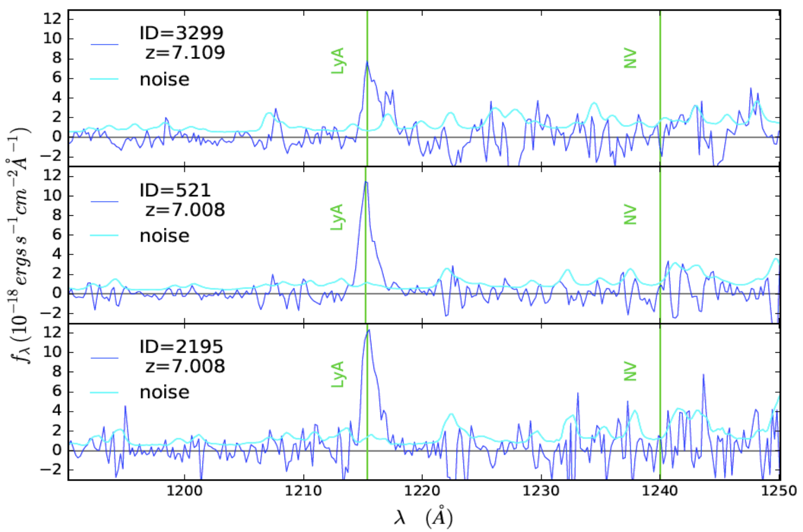
No detections from faint (Y>26.7) sources

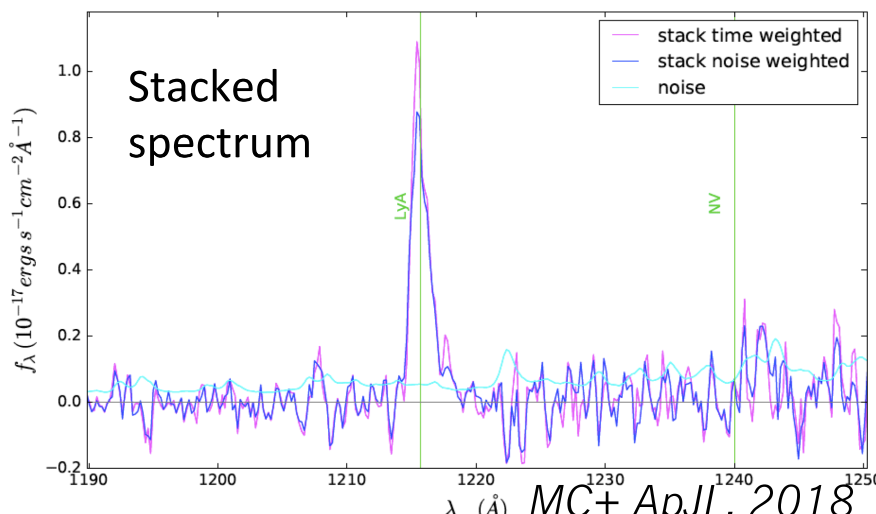
PDF(z)	Lyα visibility	Probability $P(tot=3)$	Probability $P(bright=3)$	Probability $P(faint=0)$	Expected Number $<N_{tot}>$	Expected Number $<N_{bright}>$	Expected Number $<N_{faint}>$
Flat	z=7	0.21	0.009	0.17	2.1	0.7	1.4
P(z,Y)	z=7	0.18	0.009	0.22	1.9	0.7	1.2
Flat	z=6	0.08	0.035	0.002	5.5	1.2	4.3
P(z,Y)	z=6	0.11	0.036	0.004	5.0	1.2	3.8

Comparing number of detected lines to number of expected detections under different hypothesis:

- peaked ("Flat" at z=7) or wide ("P(z,Y)") redshift distribution

- z=7 (low) or z=6 (high) line transmission through the IGM





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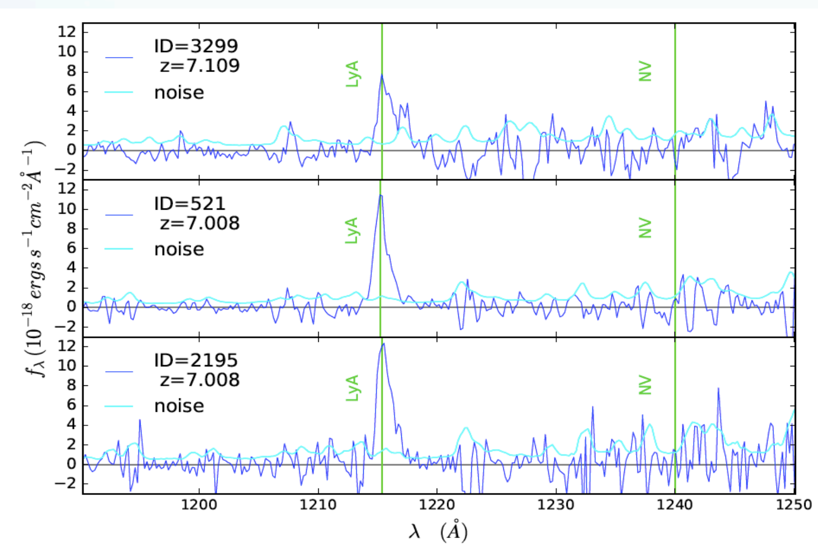
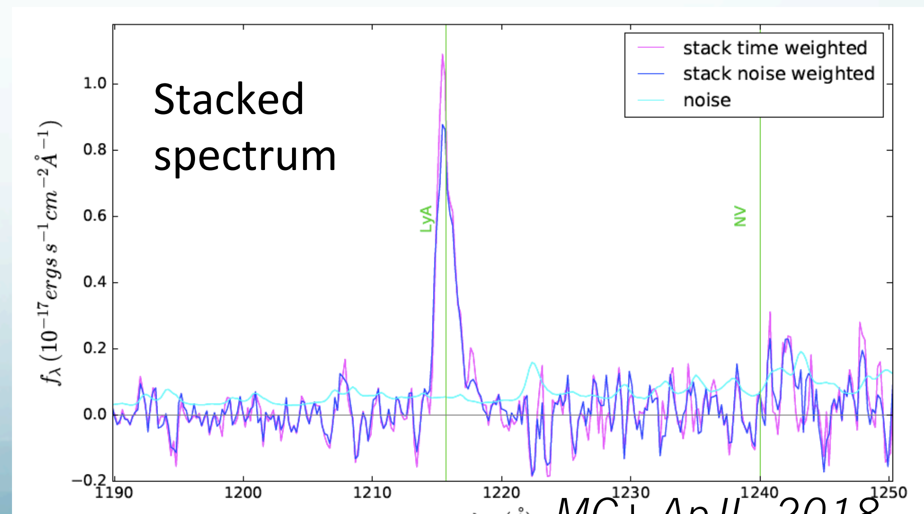
Low prob. of 3 bright (M_UV<-20.25) LAEs (**less** are expected)
→ High visibility, more consistent with a z~6 reionized Universe





MC+ ApJL, 2018

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PDF(z)	Lyα visibility		Probability			Expected Number	
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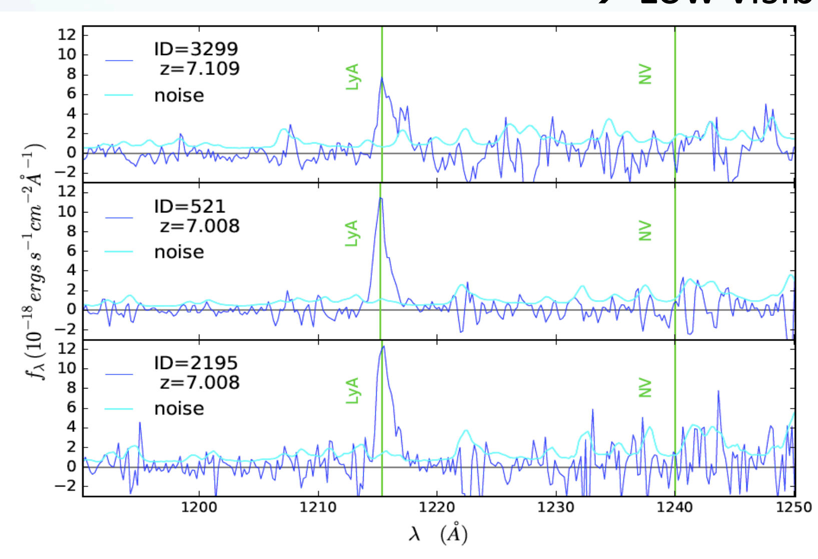
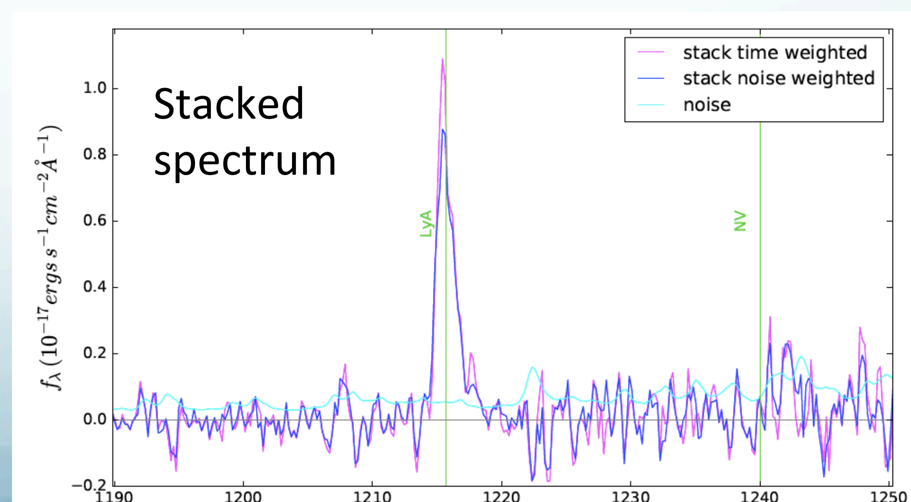
P(z,Y)	z=6	0.11	0.036	0.004	5.0	1.2	3.8

Low prob. of 0 faint (M_UV>-20.25) LAEs (**more** are expected)
→ Low visibility, more consistent with z~7 half-neutral Universe





MC+ ApJL, 2018

Possible scenarios

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Flat	z=6	5.5	1.2	4.3
P(z,Y)	z=6	5.0	1.2	3.8

❑ *Bright galaxies are in a reionized "bubble" but faint galaxies are outside*.

→ Bubbles are created by the bright galaxies alone (SFR and/or AGN), or by bright galaxies+ objects beyond the current BDF detection limit (M_{UV}>-19, e.g. Vanzella+17a,b).

→ Lya from bright galaxies is boosted by velocity offsets and/or enhanced photon production (Mason+2018, Stark+2017).

❑ *Bright and faint galaxies are all members of the reionized "bubble" but some mechanisms decrease Lyα escape from faint galaxies*.

→ Accelerated evolution of overdensity members: bright galaxies are young with high SFR, faint LBGs are more evolved and dustier.

→ Recombination of neutral hydrogen in the regions close to overdensity members, velocity shifts (higher in massive galaxies) are needed to make the line visible to us.

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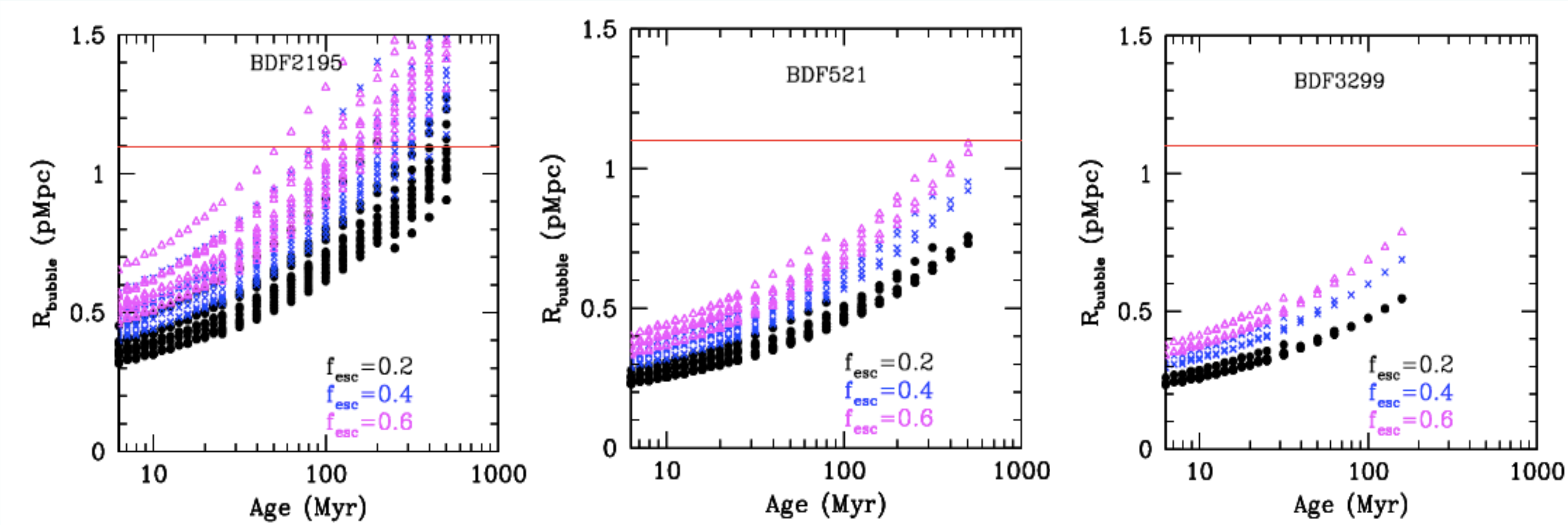
Are bright galaxies enough?



We estimate the **size of the bubble** (e.g. Madau 1999) **created by each galaxy** for all SED-fitting models compatible (68%c.l.) with the observed photometry.

Constant SFR, BPASS V2.0 libraries, Calzetti extinction. *Escape fraction of UV ionizing photons (f_{esc}) varied from 0 to 1.*

Compare to size needed to have Lyα redshifted to us (Loeb et al. 2005)

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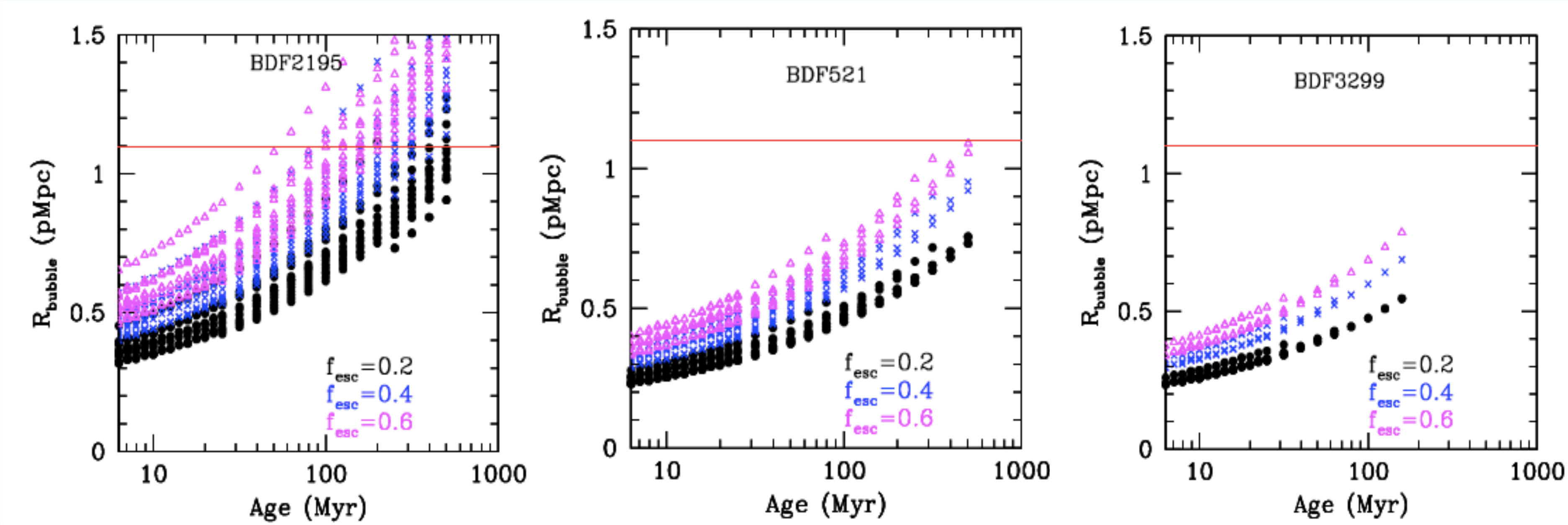
Are bright galaxies enough?



BDF521 and BDF2195 need a high f_{esc} > 20-60% to create a large enough bubble in a few 100s Myrs of constant SFR (~10-50 M_{sun}/yr).

BDF3299 is unable to create its own bubble even assuming 100% escape fraction and long lasting SFH.

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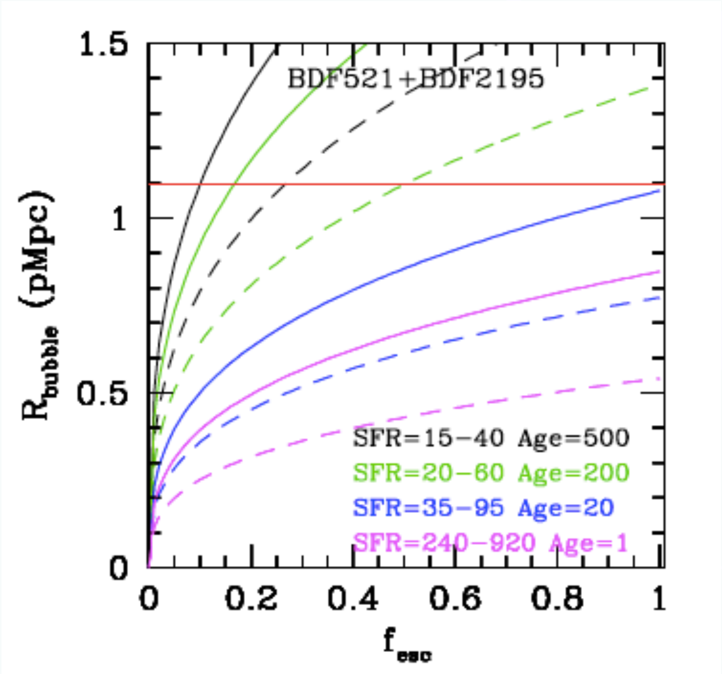
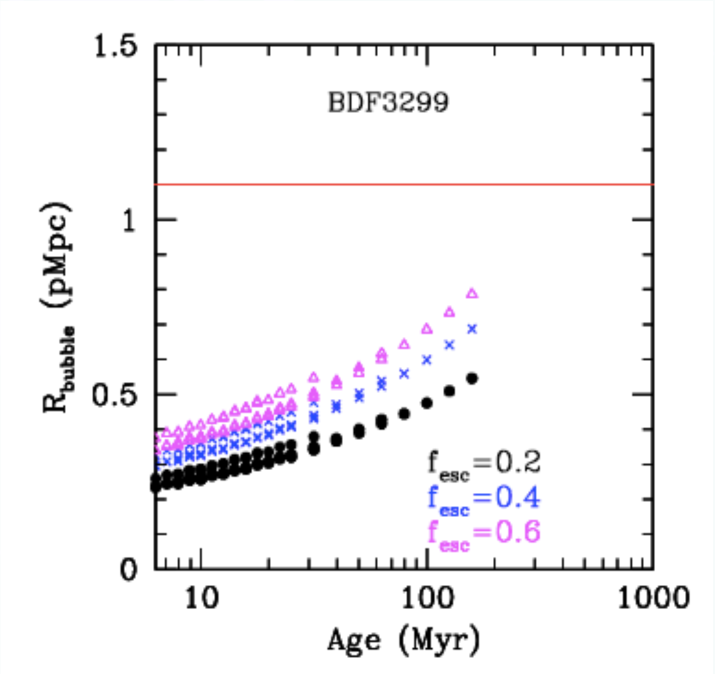
Are bright galaxies enough?





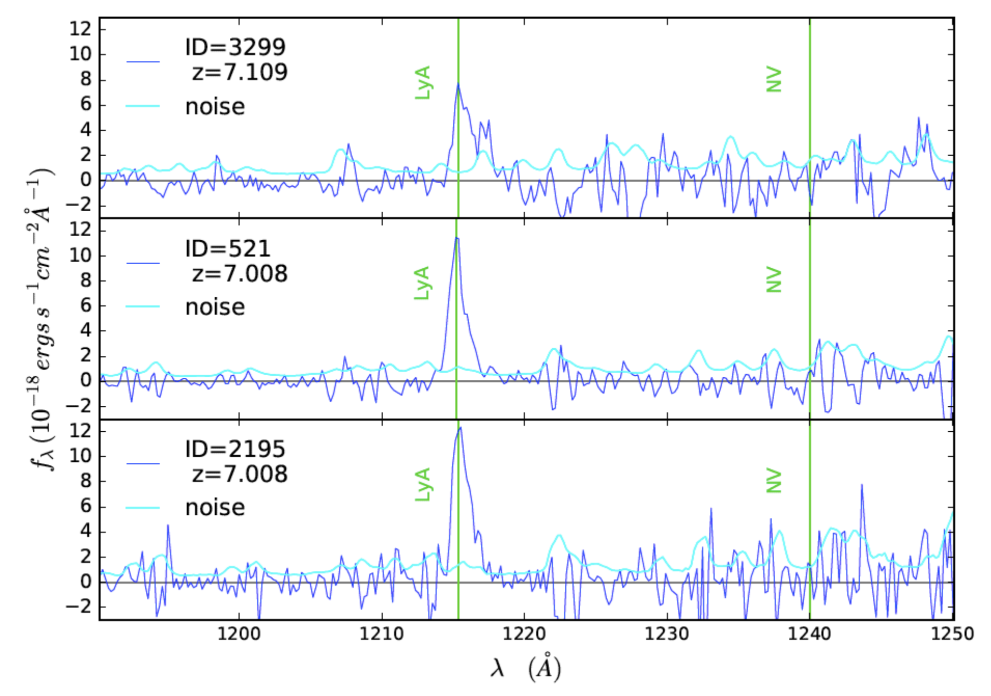
When summing the two contributions the BDF521-BDF2195 pair can create a large enough bubble with f_{esc}>10-15% and moderate SFRs over > 400Myr lifetime.

Adding the contribution of 220 km/s shifts f_{esc} <10% can do the job.

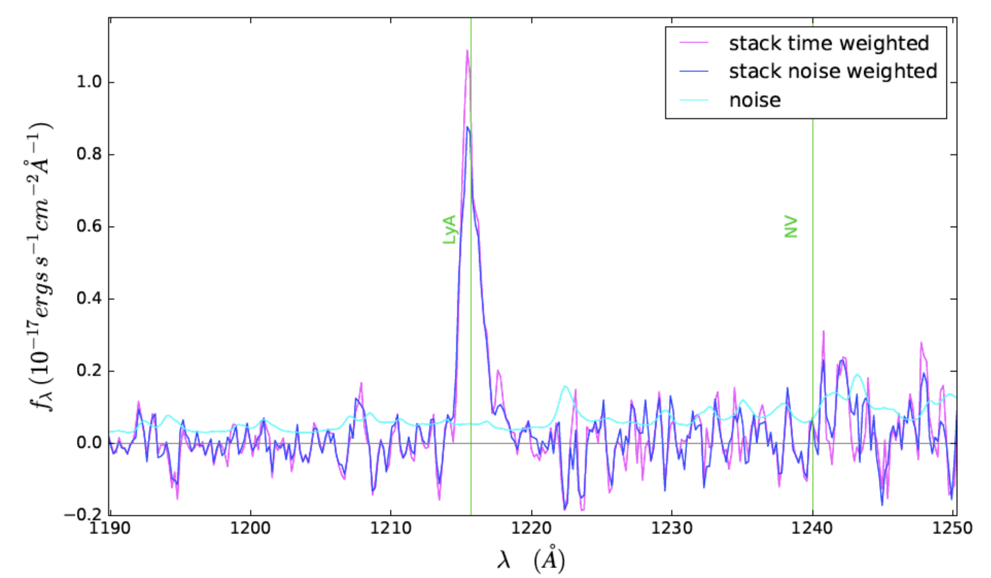
But no way for BDF3299 which is >2 pMpc distance from the pair.

MC+ ApJL, 2018

What about AGN?



Lyα/NV>~8-10 on single spectra

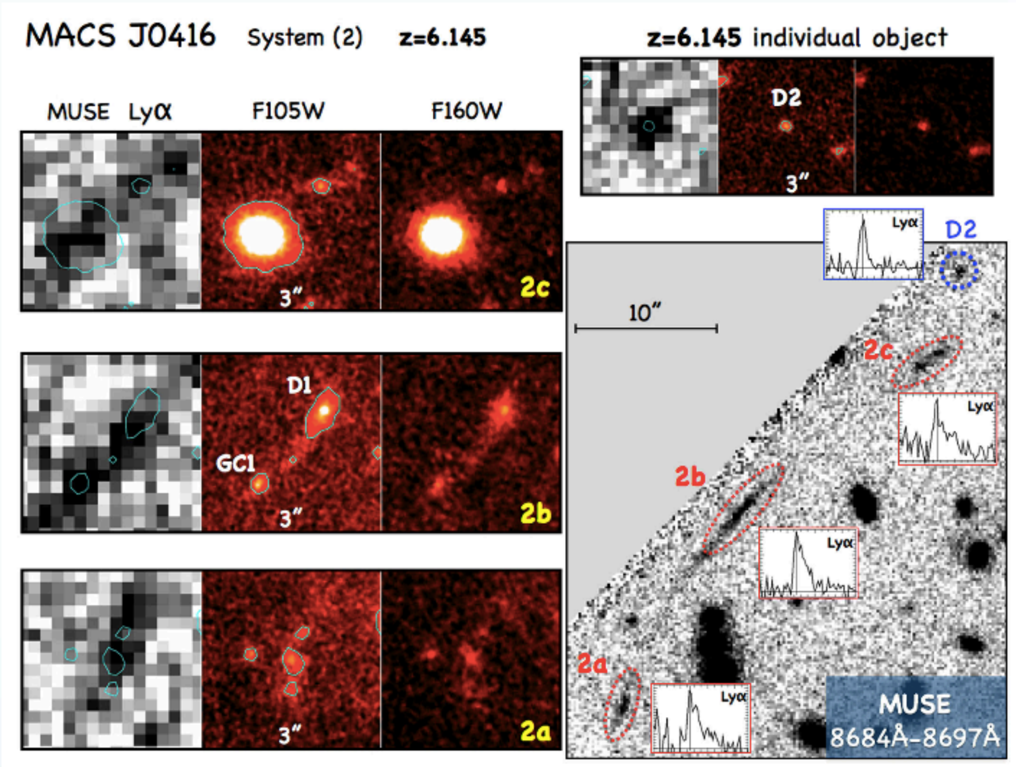


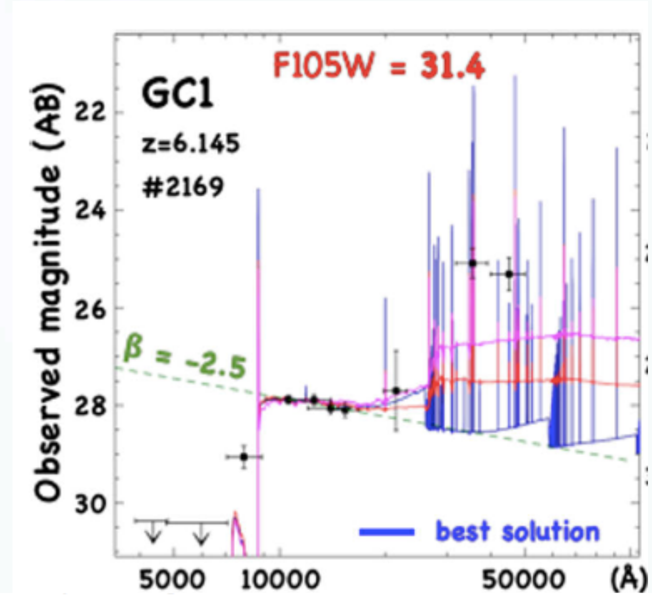
Lyα/NV>17 on stacked spectrum

Limits not enough to rule out AGN.
Not to mention past AGN activity…

MC+ ApJL, 2018

Contribution from clustered ultra-faint galaxies?





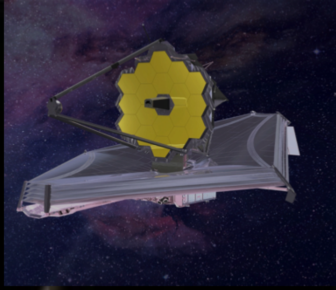
Spectroscopy from MUSE

The luminosity, mass and size range we are probing is the one predicted for GC progenitors at z>3

Vanzella et al. 2017b,c and 2018a

	Models Proto-GCs	GC1($z = 6.145$) (*)2169 04:16:11.56 −24:03:44.7	D1($z = 6.145$) 2179 04:16:11.48 −24:03:43.4	D2($z = 6.145$) 2411 04:16:10.31 −24:03:25.8
Stellar mass ($10^6\ M_\odot$)	1, 10	$68_{[21,3273]}\mu_{tot}^{-1}$	$380_{[368,585]}\mu_{tot}^{-1}$	$16_{[12,1027]}\mu_{tot}^{-1}$
SFR ($M_\odot yr^{-1}$)	0.2, 2.0	$54_{[1,165]}\mu_{tot}^{-1}$	$275_{[131,585]}\mu_{tot}^{-1}$	$5_{[0.5,48]}\mu_{tot}^{-1}$
Age (Myr)	5	$1.3_{[1,708]}$	$1.4_{[1,3]}$	$3.2_{[1,710]}$
$E(B-V)$	$\simeq 0$	$\lesssim 0.15$	0.10	0.0
R_e (UV) (pc)	16, 35(**)	16 ± 7	140 ± 13	<100
R_c (UV) (pc)	”	<30	150 ± 20	<100
Σ_{SMD} ($M_\odot pc^{-2}$)	800–1720	1400^{+2400}_{-900}	295^{+100}_{-80}	>85
Σ_{SFR} ($M_\odot yr^{-1} pc^{-2}$)	$(1.6–3.4)10^{-4}$	2.7×10^{-3}	2.3×10^{-4}	$>5.3 \times 10^{-5}$
m(1500 Å)	$\simeq$29–32	31.4 ± 0.2	29.7 ± 0.2	29.6 ± 0.3
M(1500 Å)	>−17	−15.3	−17.0	−17.1
β_{UV}	$\lesssim -2.5$	-2.52 ± 0.36	-2.40 ± 0.16	-2.85 ± 0.43
μ_{tot}	–	25.0 ± 2.5	19.0 ± 2.0	3.0 ± 0.2
μ_{tang}	–	17.5 ± 2.0	13.4 ± 1.5	1.7 ± 0.1
$f(+)/f(-)$	–	$\simeq 2.5$	$\simeq 2.5$	–

Waiting for JWST



JWST-NIRSPEC can easily detect optical lines, and look for other faint lines in the UV range. We will be able to:

① Assess whether faint candidates are members of the localized overdensity at z~7.0-7.1 as the bright ones.

② Perform accurate measurements of SFR, extinction and age (Hα luminosity, Hα /Hβ and Hα /UV ratios) to constrain re-ionization capabilities.

③ Measure velocity shifts between Lyα and UV/optical lines.

④ Probe signatures of a high escape fraction (e.g. Zackrisson+13, Verhamme+15, de Barros+16, Chisholm+18 etc)

⑤ Probe signatures of AGN or of hard ionizing stellar spectra (e.g. Stark+17, Mainali+17, Senchyna+17, Schaerer+18).

⑥ Confirm a low neutral fraction looking for blue wings in high-resolution Lyα spectra (e.g. Hu+16)

Summary and conclusions

- ✧ Three close-by z~7 LAEs in the BDF field embedded in an overdensity of faint LBGs. They are all L~L* galaxies.
- ✧ Two LAEs form a pair at ~90 kpc distance.
- ✧ Lyα fraction much higher than average at z~7 : patchy scenario (see Pentericci+14) likely due to clustering.
- ✧ Consistent with the presence of overlapping reionized "bubbles" of ~5Mpc radius.
- ✧ Puzzling lack of Lyα from faint companions: low Lyα escape from faint galaxies?
- ✧ The pair BDF521-BDF2195 can reionize their surroundings with "reasonable" f_{esc}~5-20%.
- ✧ BDF3299 would require other (ultra-faint?) sources, or AGN (but Lyα/NV>10).
- ✧ Ideal target for JWST to discriminate among various scenarios!
- ✧ Hot topic for the future: connecting galaxy overdensity and 21cm signal with SKA (e.g. Hutter+16).