Tracing the reionization epoch with Lya observations

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in collaboration with
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Timeline in cosmic history

Years since the Big Bang

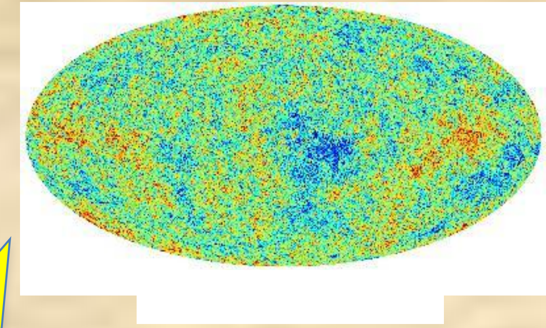
~350000 (z~1300)

~100 million (z~20-40)

~1 billion (z~6)

~13 billion (z=0)

Cosmic Microwave Background



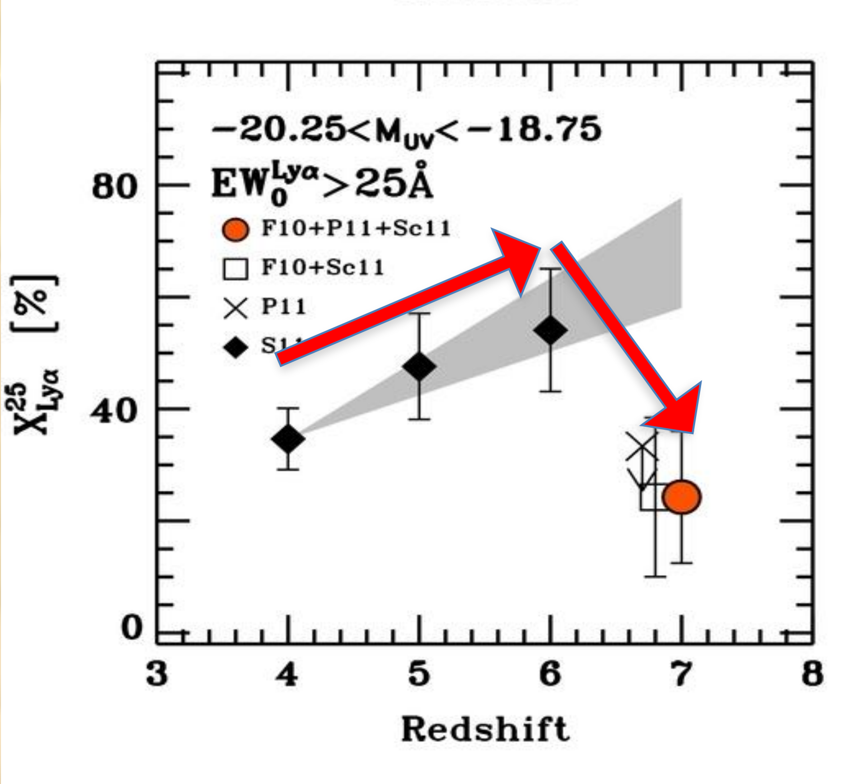
GP trough in QSO spectra
LAE clustering/ LAE LFunction
Fraction of Lyα emission in LBGs
GRBs - Lyα Dark Gaps
QSO damping wing

UV/Optical/IR

Probing reionization with the Lyα fractions in LBGs: when exactly does the Lyα decline?

Early results by several independent groups indicated that the fraction is rising up to z=6 and then sharply declining (Stark et al. 2010, Fontana et al. 2010, Pentericci et al. 2011, Ono et al. 2012, Schenker et al. 2012, Ono et al. 2012,Cassata et al. 2012, Treu et al. 2013, Caruana et al. 2013 etc etc)

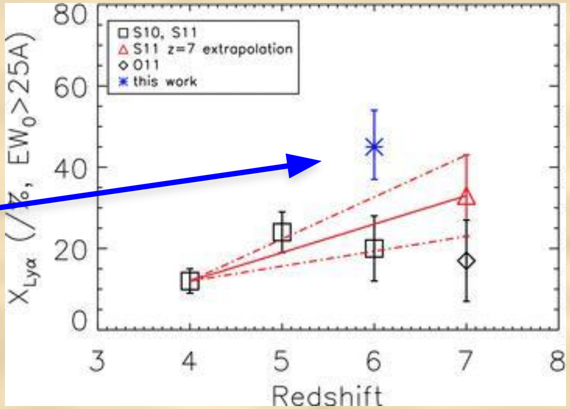
The rise and fall of Ly α is particularly pronounced for the faintest galaxies (but at these magnitudes samples are smaller and observations more difficult)



CANDELSz7: an ESO Large Program to probe the reionization epoch

A.The early samples were **small** and **very heterogeneous** in terms of :
-selection (color vs zphot) , observational set-up (i.e. redshift coverage) & Lyα EW limit reached

B. The distribution of Lyα was still uncertain also at z≈6 (e.g. Curtis-Lake et al. 2012 claimed a much higher fraction of emitters) hence the real drop from z≈6 to z≈7 might change



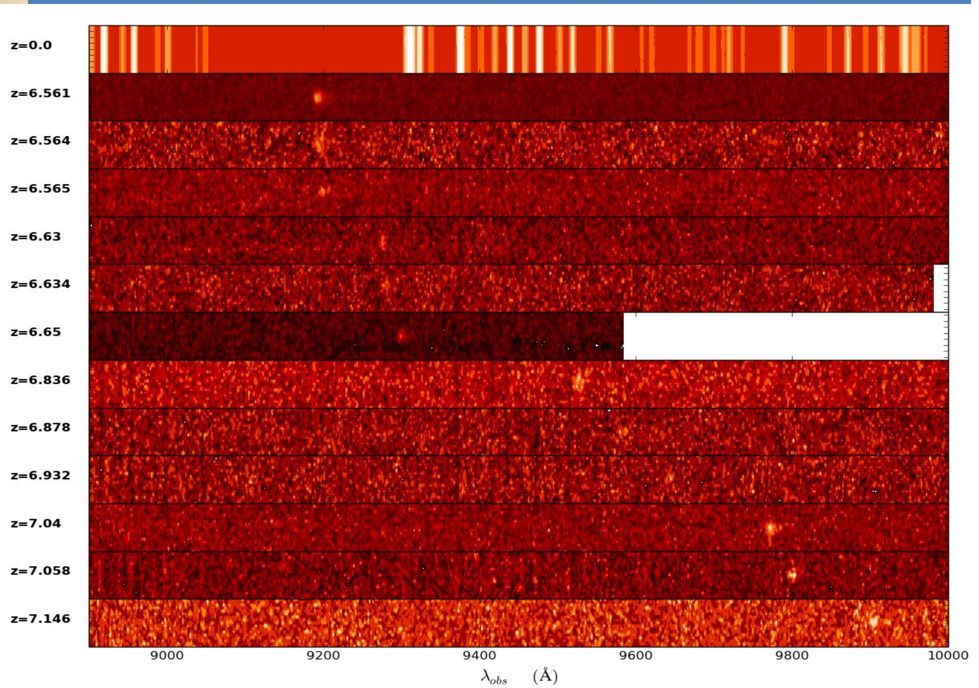
C. Bias could arise at z≈6 samples from the selection in z-band (which contains the Lyα) as done in early surveys

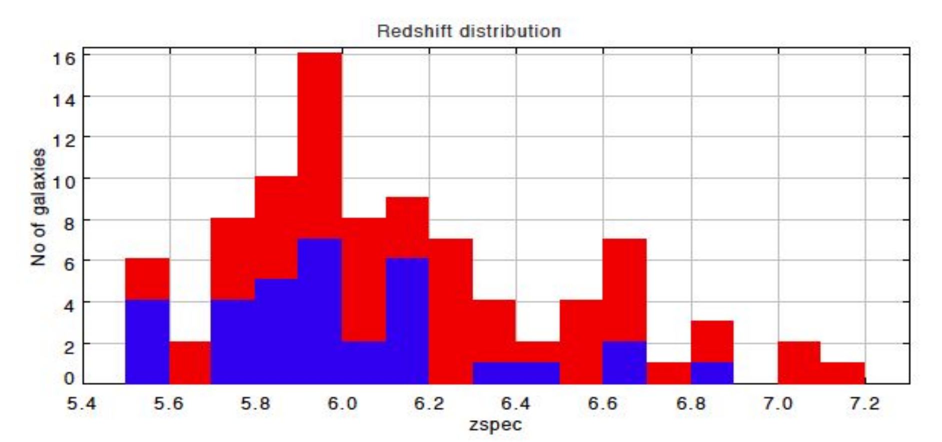
D. Large field to field variation (e.g. Ono et al. 2012) were observed probably due to spatial fluctuations depending on the degree of inhomogeneity of the reionization process (e.g. Taylor & Lidz 2014)

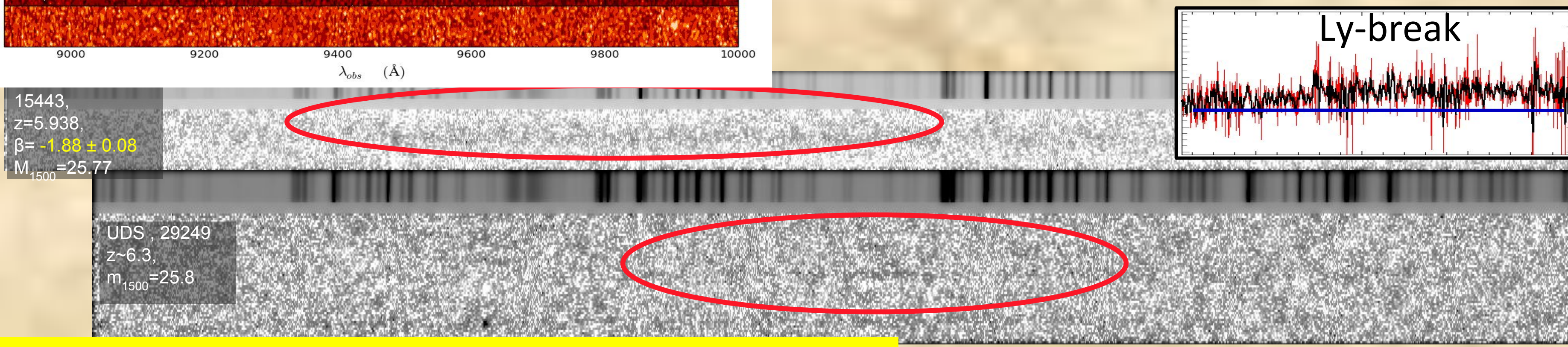
To overcome these limitations we carried out CANDELSz7 an ESO Large Program with FORS2 to observe 160 galaxies at 5.5 < z < 7.3 in COSMOS/UDS/GOODS-S selected from the CANDELS catalogs to determine a solid and unbiased statistics of Lyα fractions in this redshift range. *The selection band (H-band) is independent of the presence of Lyα @z=6 & z=7.* ***The survey was carried out in excellent conditions 0.5”-0.8” and using*** **t_exp =10-15 hours.**

CANDELSz7 results: 65 newly confirmed galaxies

We have confirmed 17 new galaxies at 6.5 < z < 7.2 all with Lyα emission, and 48 new 5.5<z<6.5 galaxies mostly with Lyα emission







We measure redshift for faint (mag=25-26) galaxies with no Lyα emission up t z=6.3-6.4. Non trivial. <u>Half of the LBG population at z=6</u>

Pentericci+2018 submitted to A&A
Data are being release through the ESO archive

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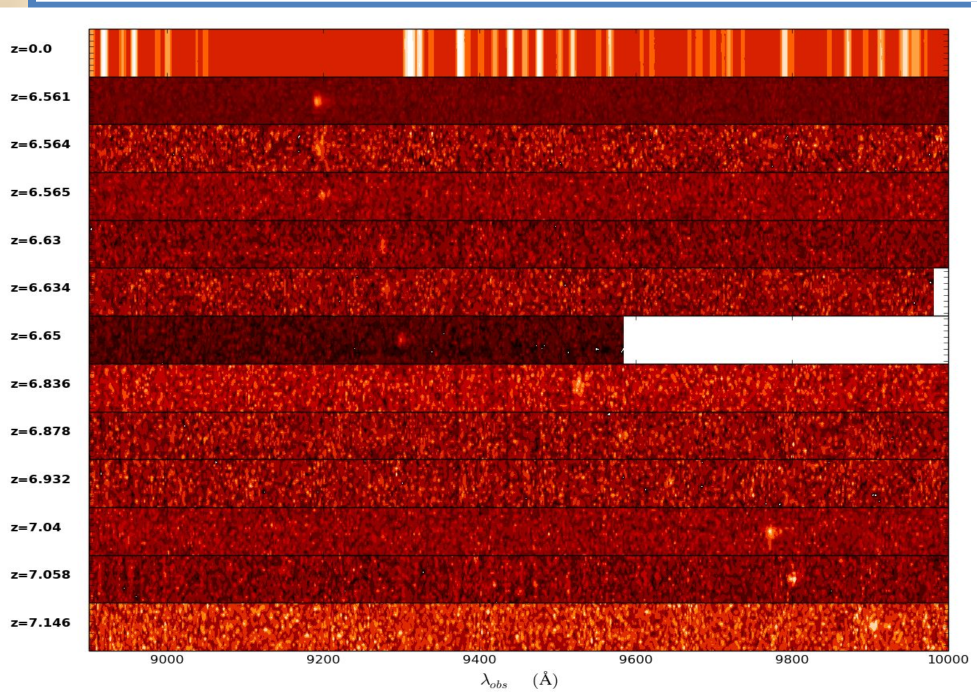
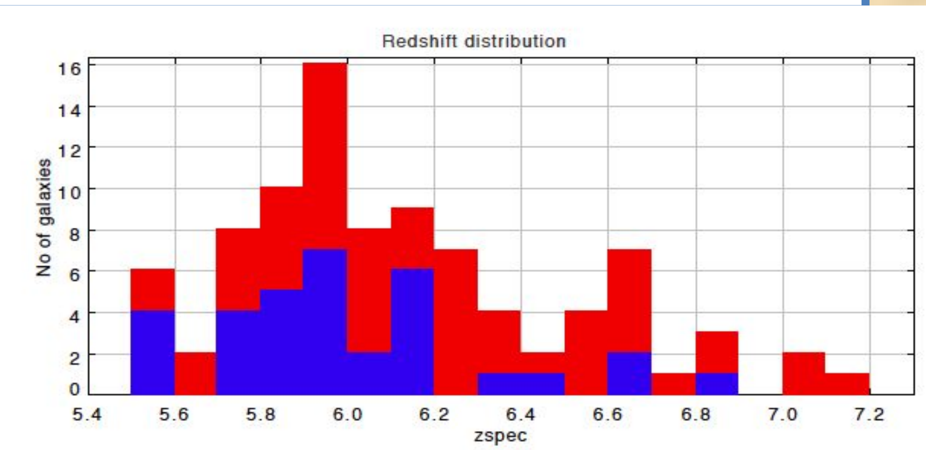
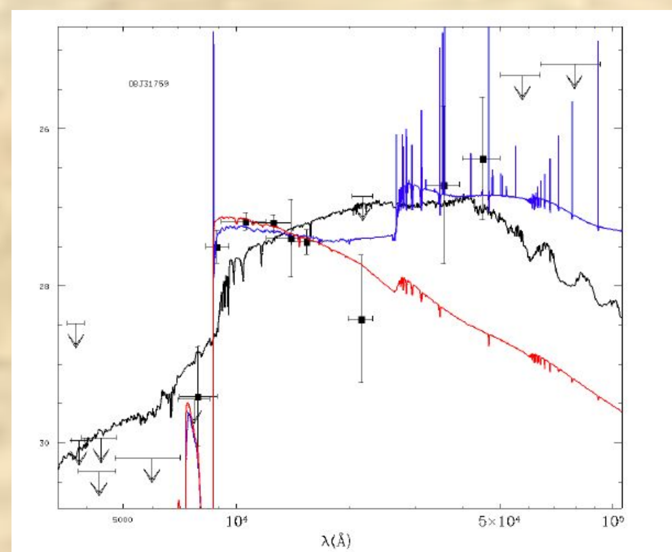
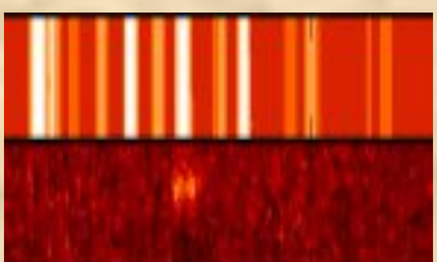




Thanks to our resolution we are able to resolve the 3727-3729 A doublet and get rid of the (very few) interlopers



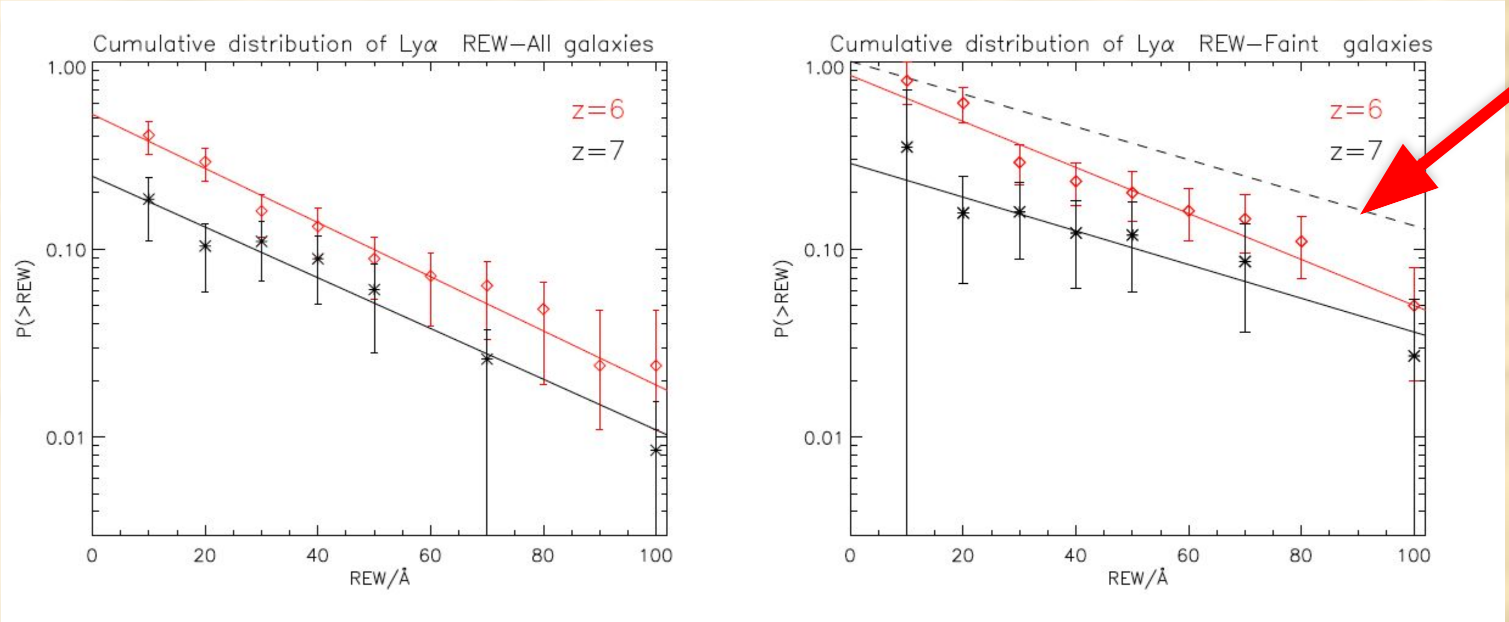


Puzzling source with CANDELS photometry that indicates with high confidence a z=6.4 solution but with double emission line

CANDELSz7 results: EW distributions @z=6 and z=7

Including new Large Program data + earlier & archival observations (LP+2014,LP+2011,Vanzella+2011,2009, Caruana+2012) we have assembled a sample of >135 z-dropouts & 130 i-dropouts in 8 independent fields, mostly observed with the same instrumental set-up and with similar limiting flux.

For the undetected objects we set firm limits on the Lyα EW using very accurate simulations (see Vanzella+14, LP+14)

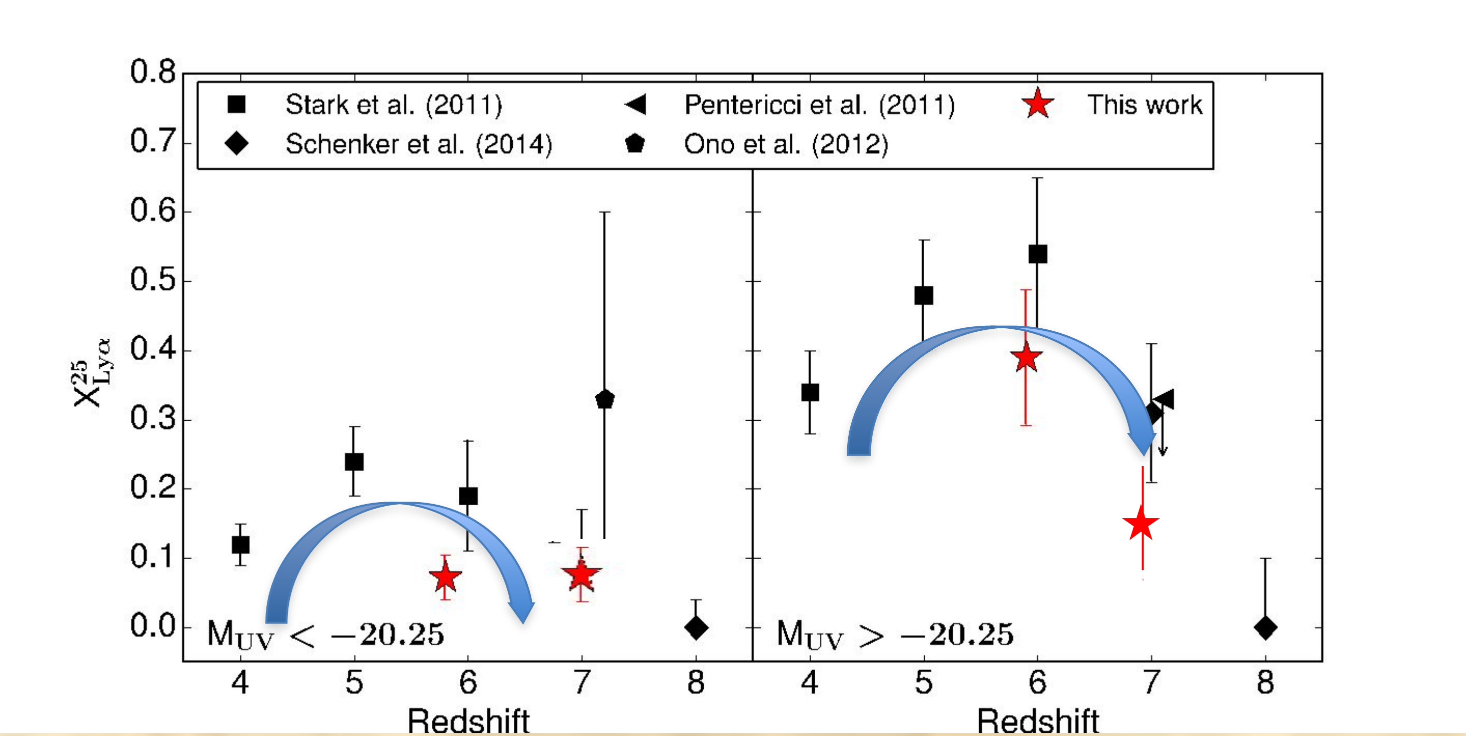


Dashed line is the previously assumed z=6 distribution (Dijkstra+16)

Cumulative distributions of rest-frameLyα EW for faint (right) and all (left) galaxies at z=6 and z=7

CANDELSz7 results: fractions of Lya emitters

Our fractions are lower than previous determinations at z=6 and similar or slightly lower at z=7



Why??

- Field to field variations are more than a factor of >2 : e.g. @z=6 f_{Lya}>25 Å goes from 35% (UDS field) to 13% (COSMOS field) → we now use 5 independent fields at z=6 and 8 fields at z=7 to mitigate cosmic variance .
- The detection in pre-CANDELS surveys was done mostly in the z-band: faint galaxies with bright Lyα in the range z=[6-6.5] are promoted into the detection band and push up the fraction of strong Lyα emitters at z=6

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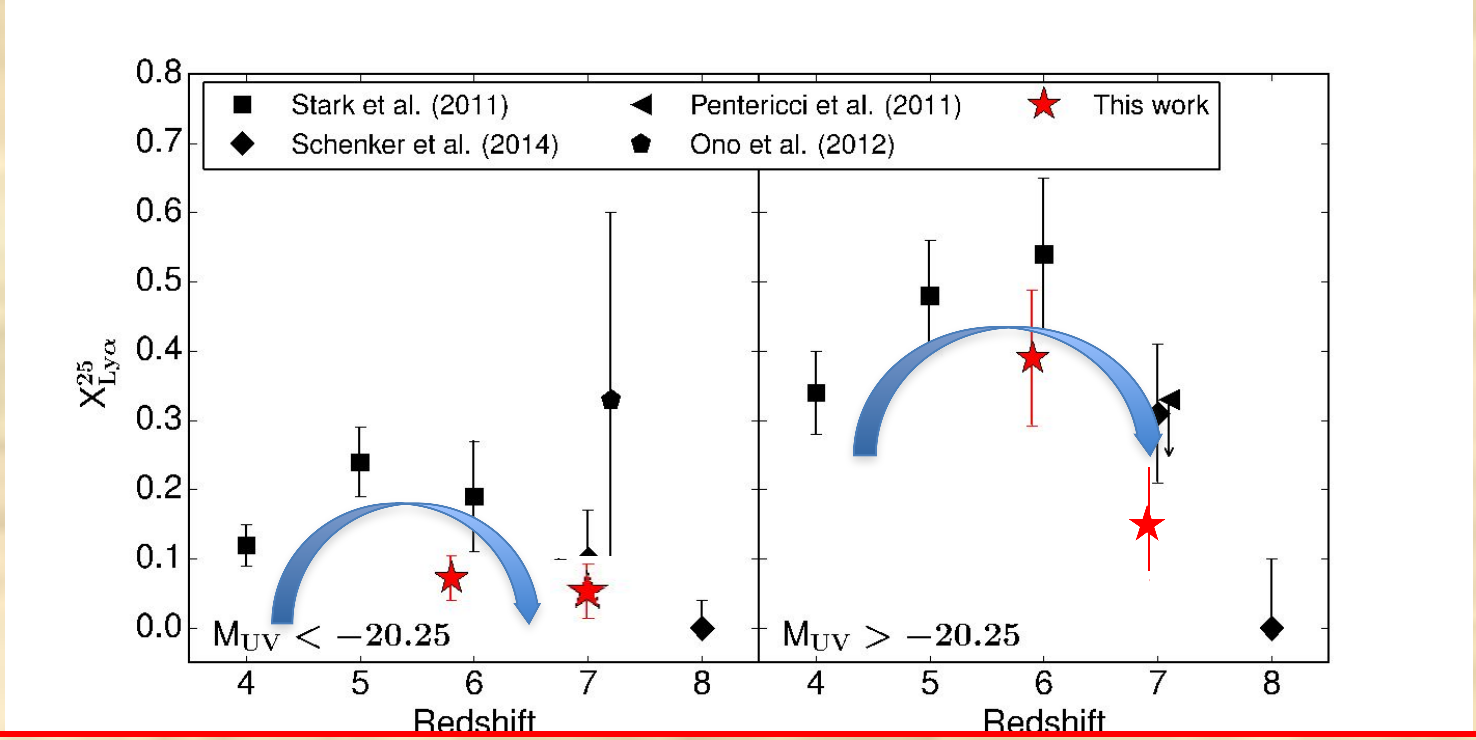
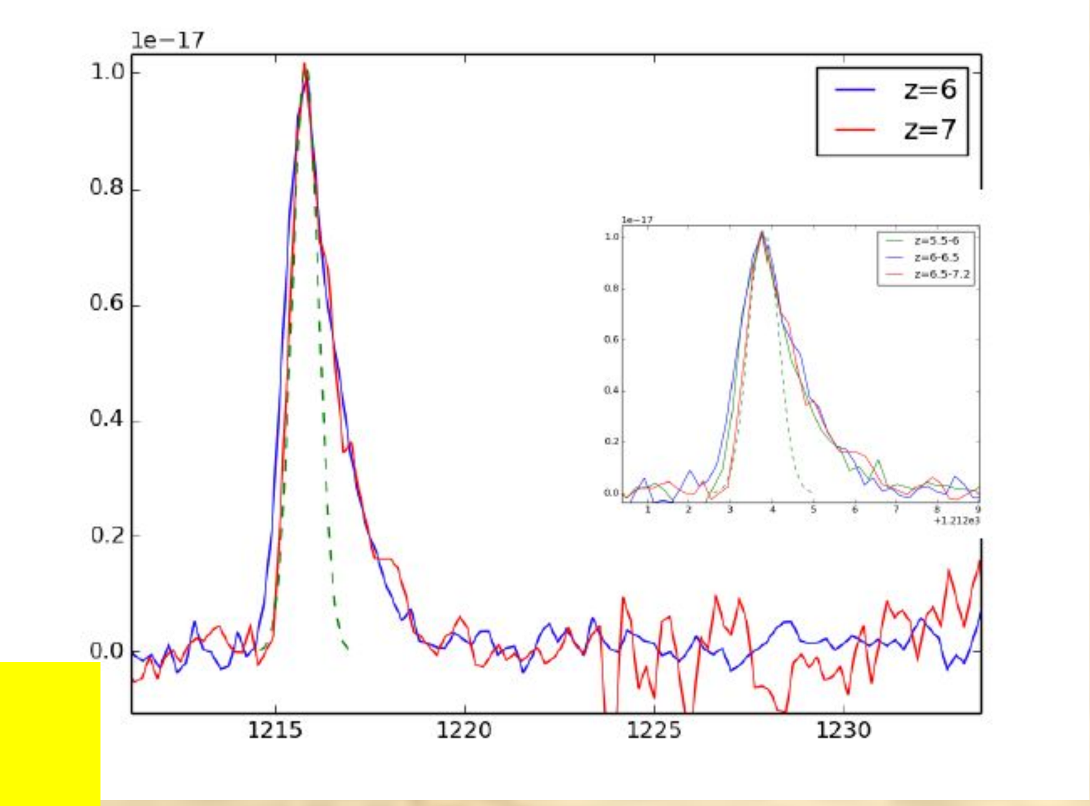


Our results indicate that the rise in the fraction of Lyα emitters might actually stop at z > 5 with a flattening (for faint sources) or downturn (for bright sources) already at z=6

If the visibility of Lyα is only driven by IGM then this could indicate a more extended reionization process and a less rapid evolution of the IGM neutral hydrogen fraction

CANDELSz7 results: spectral stacks

Including previous data with FORS2 observations **taken with the same 600z grism** and using only high quality spectra we produced stacks at z=7 (19 galaxies) and z=6 (50 galaxies)



The blue side of the Lyα emission line is completely erased at z=7, where it is consistent with the instrument profile, while in the lower redshift stack some emission is still present at a significant level. Both stacks have a similar red extended tail.

Since the galaxies in the two samples span the same range of M_{UV} and SFR, the difference in the observed shape of the Lyα profile might be due to the impact of the IGM (e.g. Laursen+2011)

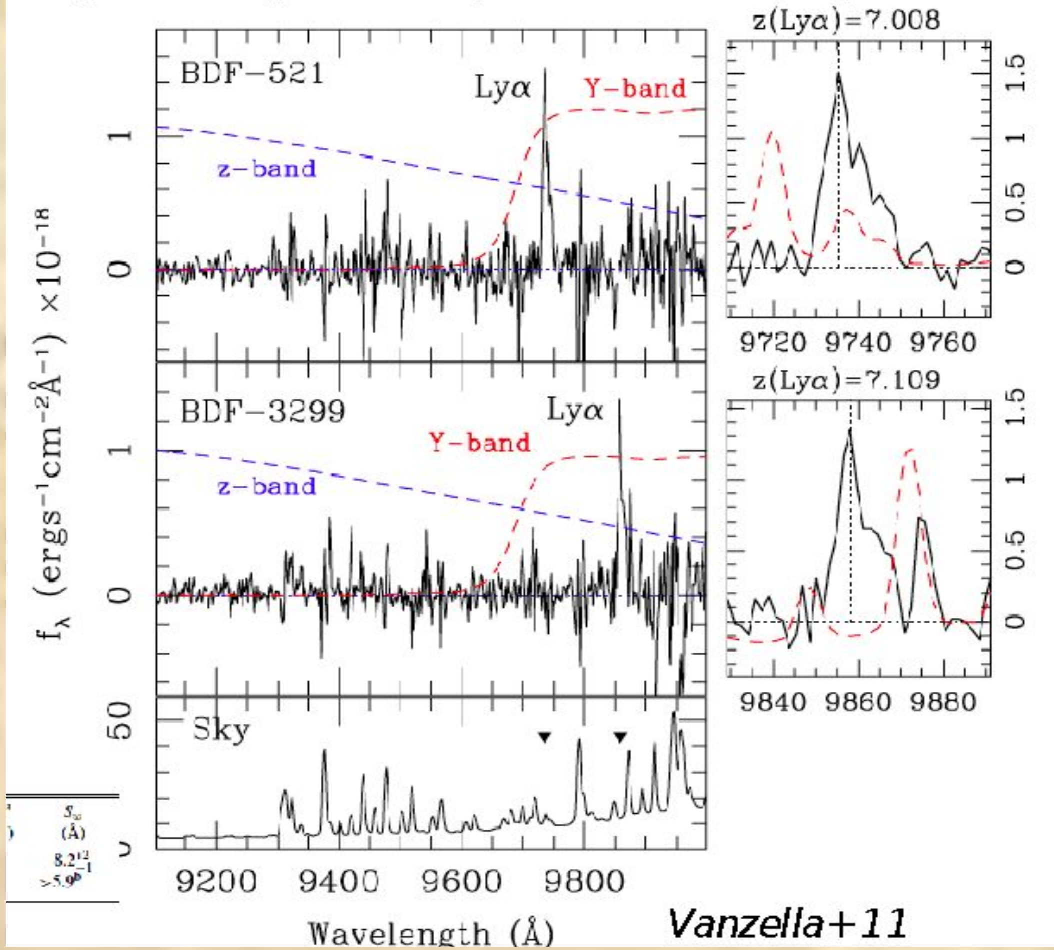
A space oddity: clustering of Lyα emitters at z>7

In the paucity of Lyα emitters at z=7 the BDF field stands out as the only field with two bright emitters amongst the 8 LOS investigated in LP14 + Large Program+others

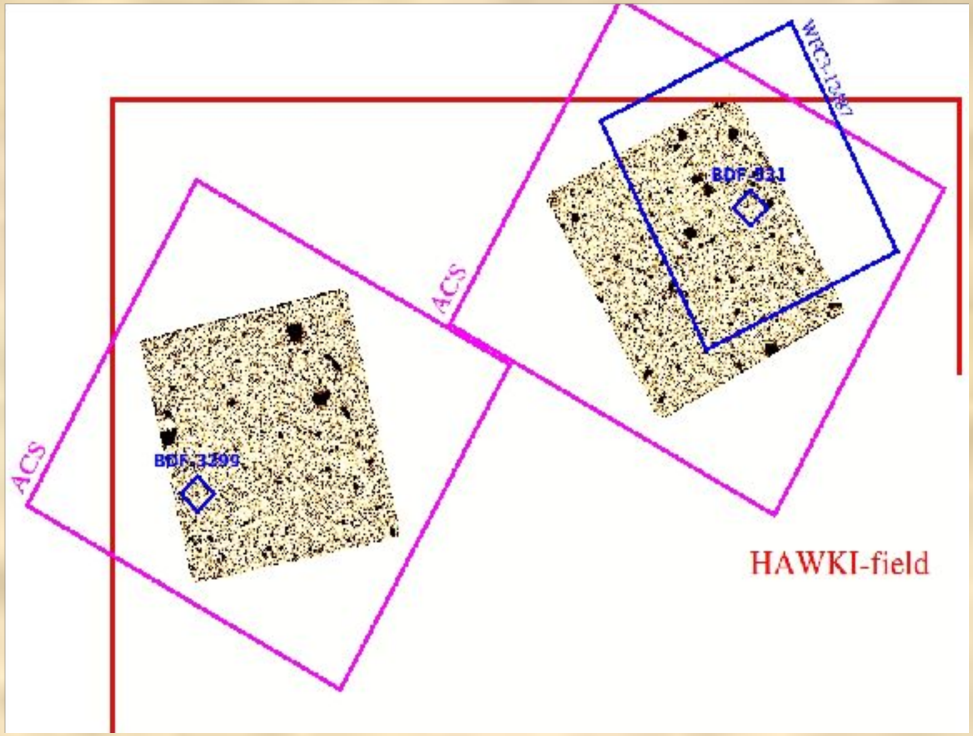
The 2 sources have Lyα EW>50Å and are separated only by 4Mpc (proper)

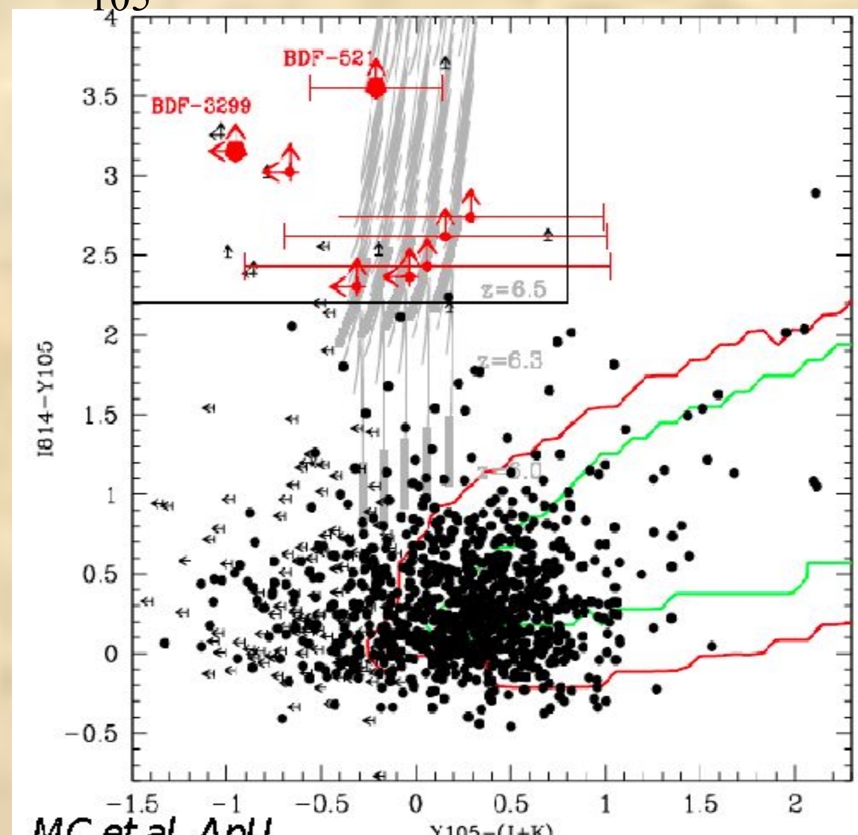
Their L_{uv} cannot build a large enough HII region to explain the line visibility (Vanzella et al. 2011) even assuming f_{esc} of ionizing photons =1

Are additional sources required? (e.g. Dayal et al. 2009)

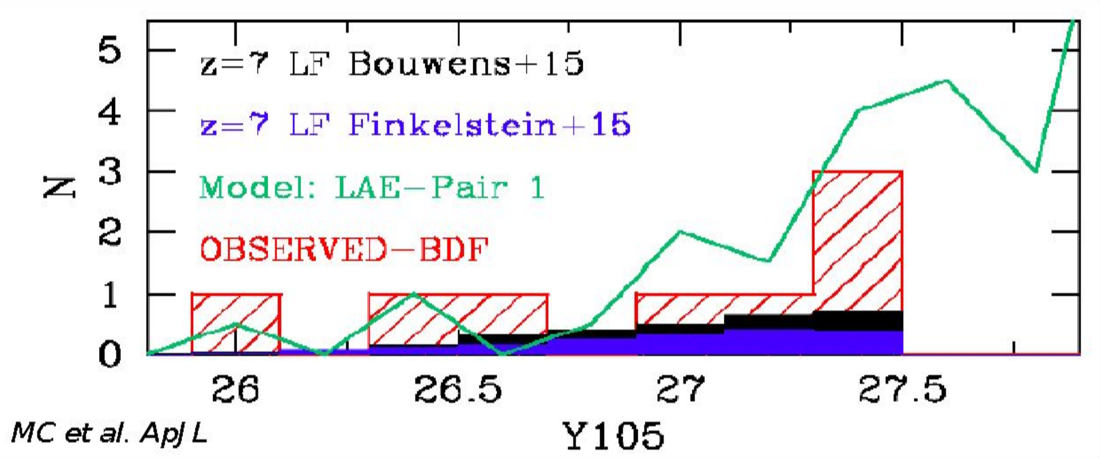


With an HST Cycle 22 program (PI M. Castellano) we searched for additional fainter sources in the proximity of the two bright emitters. Deep observations in : V_{606}, I_{814} and Y_{105}





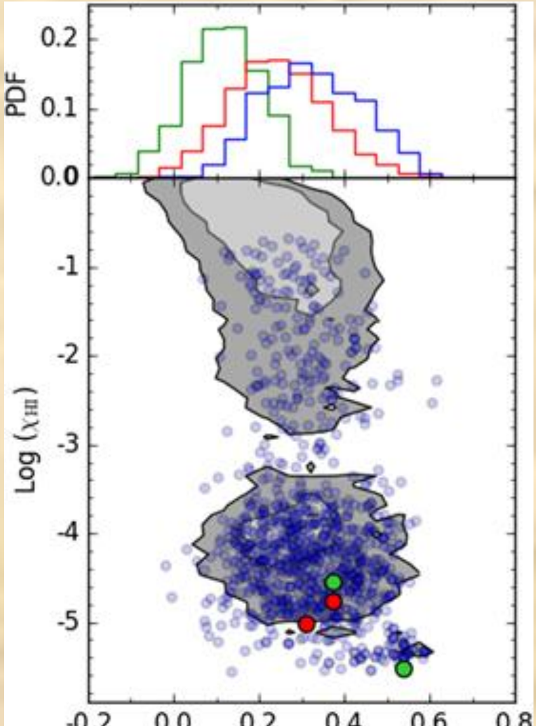
6 new robust z-dropouts were identified at Y_{105}≈26.5-27 at S/N >10 i.e. 1 mag deeper than previous HAWK-I data plus 23 additional candidates with S/N> 5



The BDF field is a factor 3-4 over-dense compared to average
No other such clustering is observed around the GOODS-South z=7 sources where similarly deep data exist

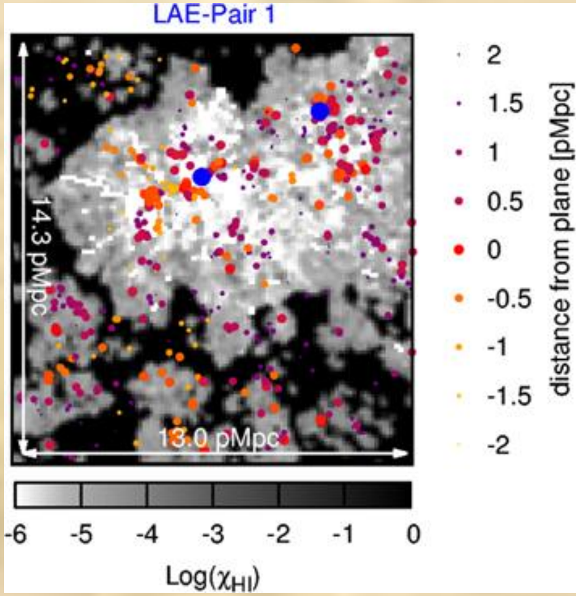
Castellano+2016

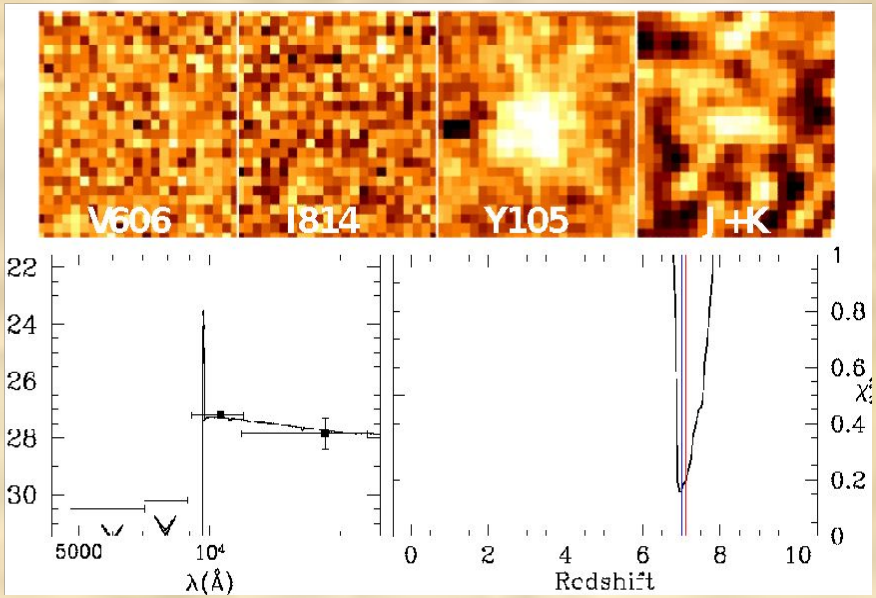
Does galaxy density drive reionization?



⇦ Hydrogen neutral fraction versus galaxy overdensity in our cosmological simulations

Using SPH models (Hutter+14) we searched for analogs of LAE pairs as bright as our two initial BDF emitters: these pairs live in dense region which are highly ionized already at early epochs (log X_{HI} <-4.5)





Stacking the 6 more luminous LBGs candidates still shows a non detection in the V_{606} and I_{814} filters at >30.2 mag and a 2 sigma detection in the HAWKI J+K data

→ I_{814}-Y_{105}>3

→Best fit photometric redshift for the stack is zphot=6.95 consistent with the two previously confirmed emitters

Castellano+2016

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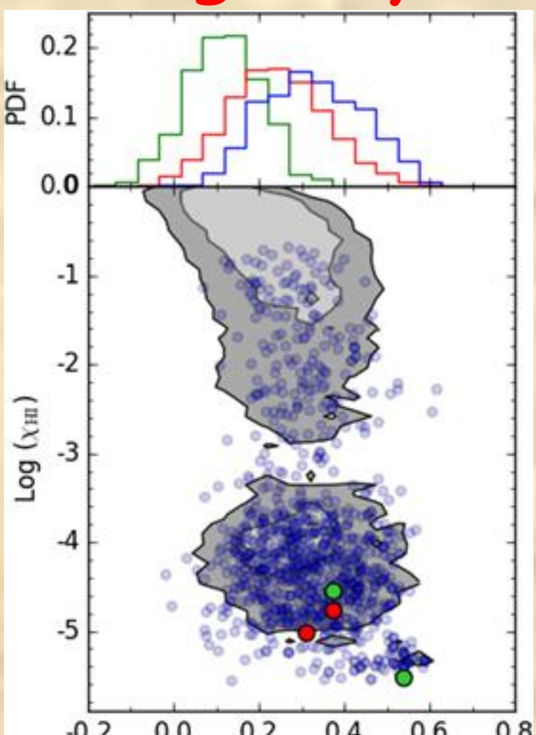

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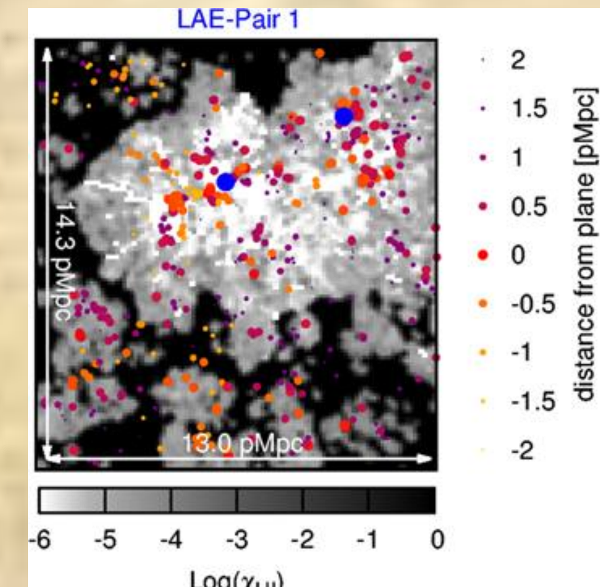
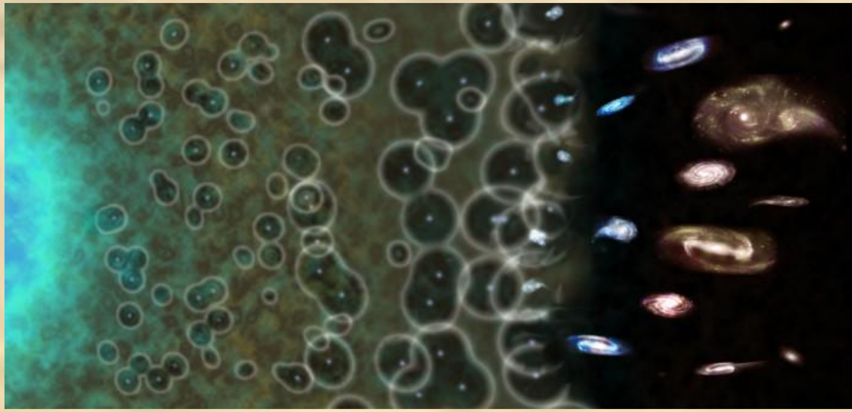
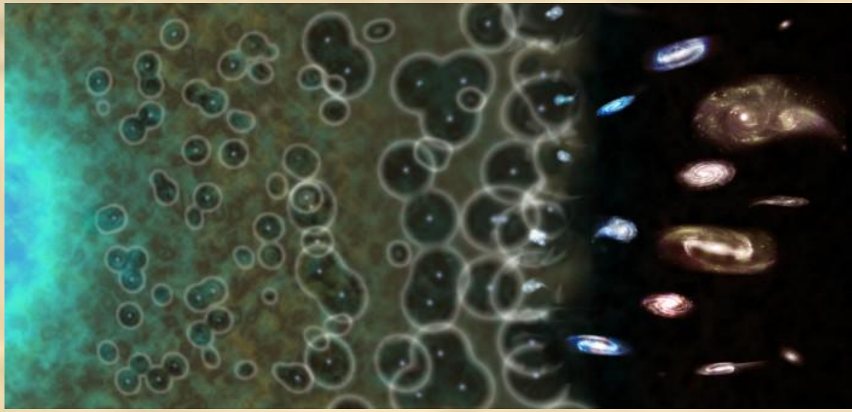




Models give support to the presence of an ionized bubble of 4-5 Mpc, linked to an early over density. This is the first time we might establish a connection between galaxy overdensity and ionized fraction indicated by enhanced Lyα visibility

->If the scenario is correct the fainter companion sources should also show a higher visibility of Lyα compared to similar z=7 sources located in average field → ***hard but not impossible to test with spectroscopy!!!***



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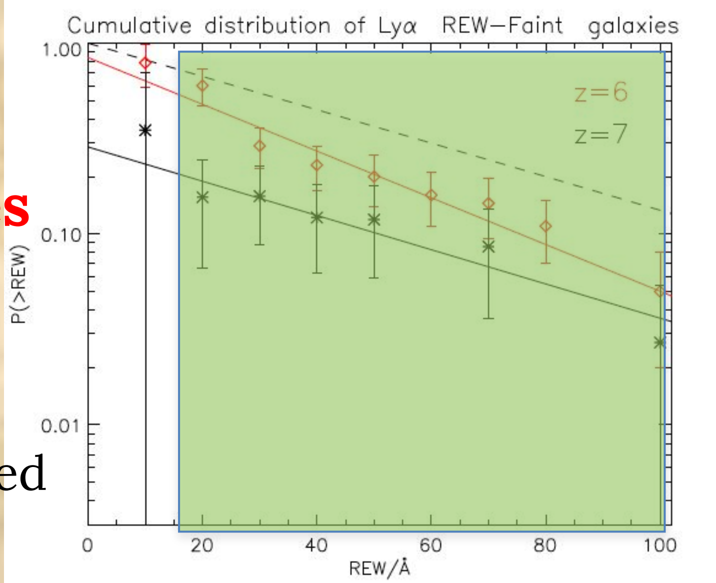
3σ Lyα EW limit → 10Å to 25Å. We expect:

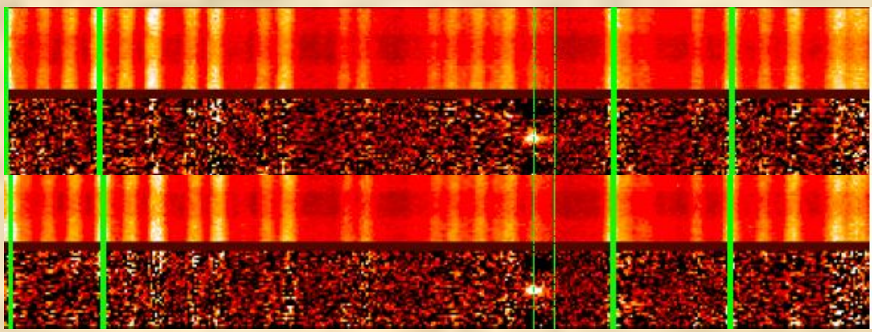
≅1 faint emitter if the local neutral fraction is similar to the average @z=7

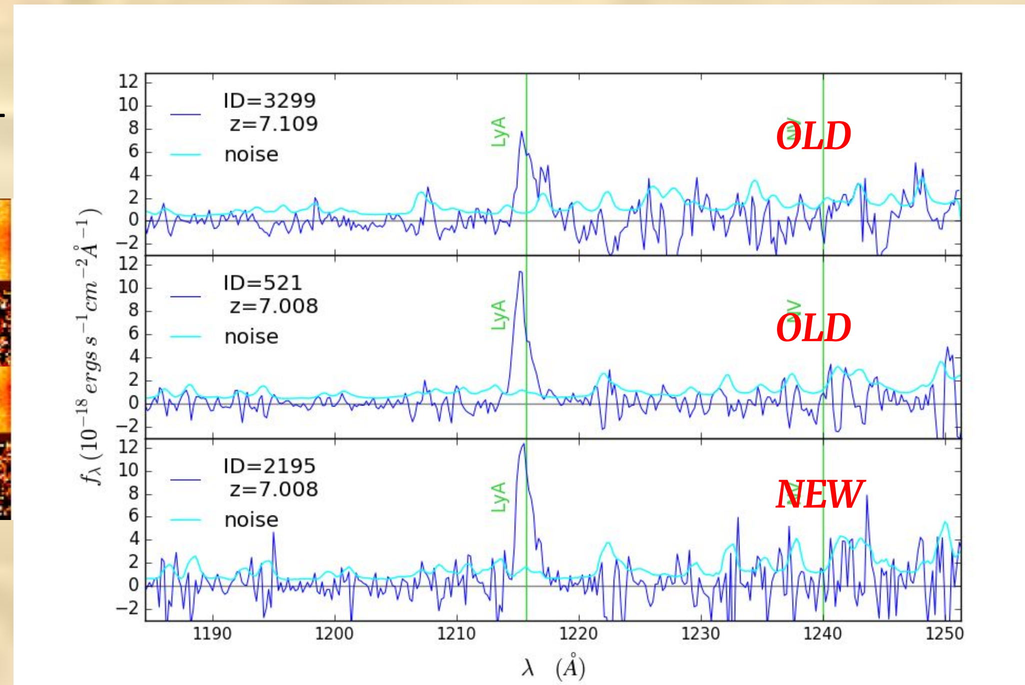
≳ 5 faint emitters if the bubble is almost totally ionized and the Lyα visibility is similar to the average @z=6

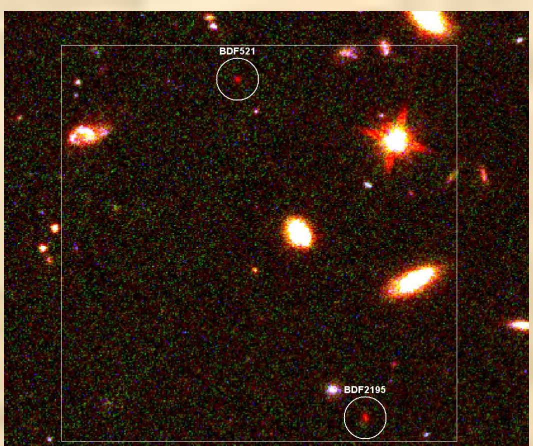


Surprisingly we confirm only 1 new galaxy @z=7.004 with very bright Lyα emission line and very close (17” i.e. less than 100 kpc) from one of the previously known emitters, BDF521 (z=7.008)

The line profile of the newly confirmed emitter is slightly different from BDF521 which has a more extended red tail







HST three color image. The box size is 100 kpc (physical) and contains two of the three confirmed emitters

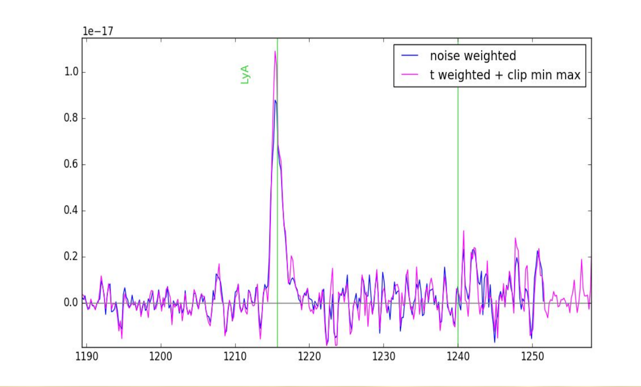
M. Castellano LP et al in preparation

No faint Lyα emitters → the Lyα visibility in the fainter sources in not enhanced despite the much higher density of galaxies and the presence of three bright sources.

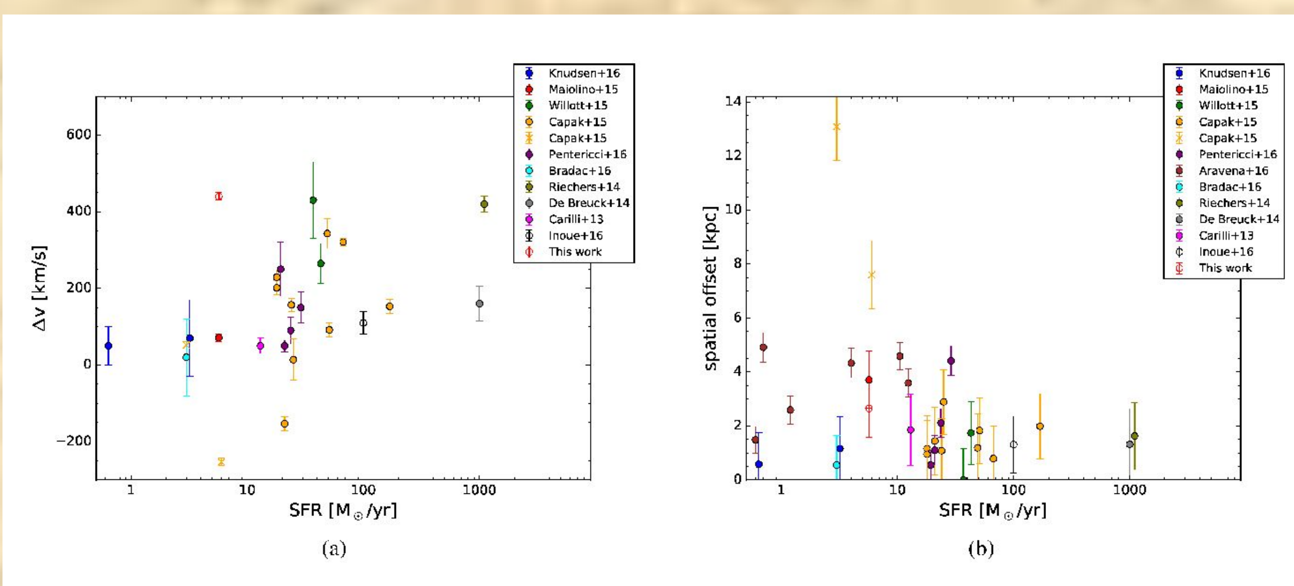
Possible explanations

The visibility of Lyα in the bright sources is enhanced because their Lyα have larger outflows due to increased mergers in the overdense region (*partially in contrast to the BDF 3922 ALMA [CII]158μm observations...*)

- Since the region is overdense the galaxies are more evolved than in the field : the faint sources with no Lyα are actually just the reddest ones and we see Lyα in the few that are experiencing their first star-burst and are not dusty
- The region is so overdense that the hydrogen recombination rate is higher than in the field and Lyα from faint galaxies is scattered away
- The 3 bright sources are AGN that carved their own ionized bubble (but *no sign of* NV *in individual spectra or in the stack Lya/*NV>18)
- The 3 sources have a combination of very high ionizing efficiency and f_{esc}
- Something else we haven't figured out...

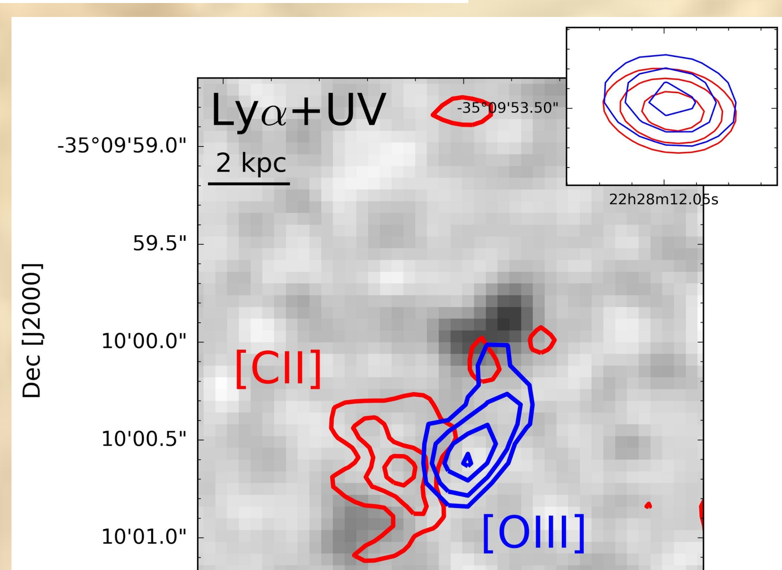


A way to probe the Lyα outflows is through ALMA observations: however spatial offset of [CII] emission at z>6 might complicate the interpretation of data (Carniani+2107)



An intriguing hypothesis is that we are starting to observe different components of primeval galaxies in the early stages of their formation

BDF 521@z=7.08 shows [CII], [OIII] and Lyα+UV all coming from different spatial regions (Carniani+2017)



Summary

- The redshift at which the Lyα emission in LBGs peaks might be below 6: this might point to a more extended reionization process but the observations need to be better interpreted with models

- We are starting to identify the first over-dense/reionized regions close to the reionization epoch: however results from spectroscopic observations are puzzling

- [CII]158 is a great tool for redshift identification and to probe of galaxy conditions (e.g. Lyα outflows) in the reionization epoch