# A large spectroscopic survey of galaxies in the reionization era

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with L. Pentericci, E. Vanzella, A. Fontana, S. De Barros, F. Marchi et al.

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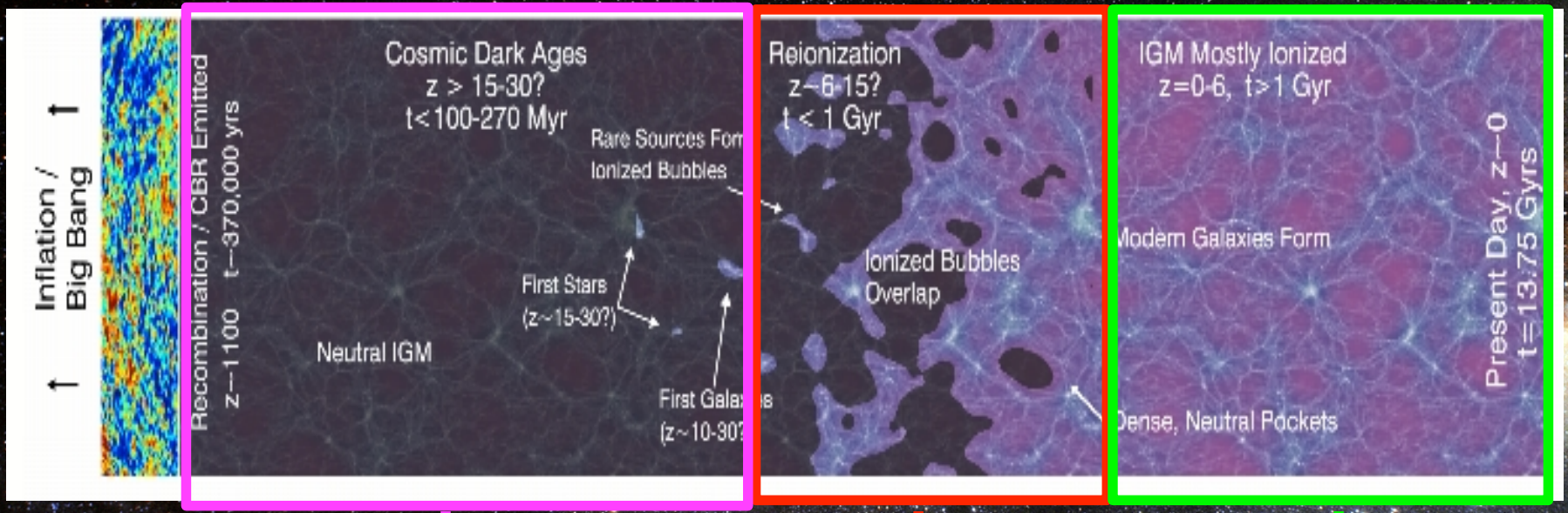
# A synthetic view of cosmic history




Dark Ages: Universe is mostly neutral, very first stars form

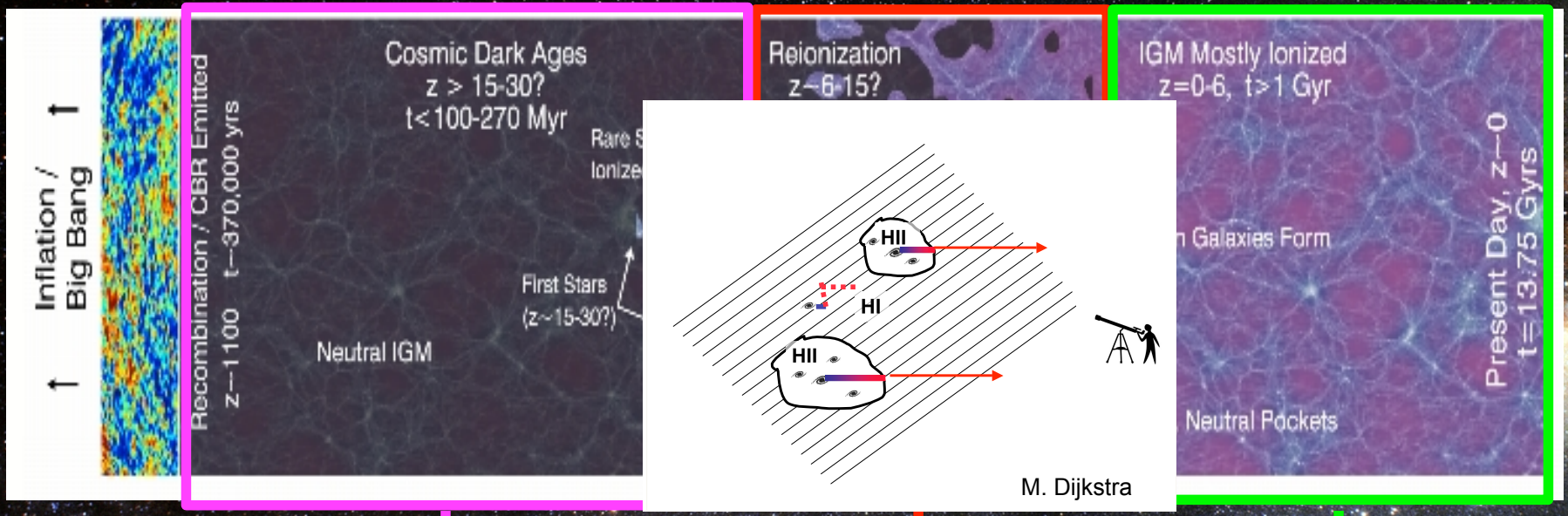
End of dark age: first PopIII dominated galaxies (JWST, EELT)

Reionization Epoch:

Star forming galaxies now observable from ground (VLT, SUBARU) and space (WFC3@HST)

The ionized Universe

# A synthetic view of cosmic history

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Reionization Epoch:

The ionized Universe

**Lyα spectroscopy provides information on reionization timeline and topology**

# CANDELSz7 - probing the reionization epoch with deep spectroscopy (ESO Large Programme)

A deep survey of galaxies at z~6-7 with VLT-FORS2 (LP 190.A-0685, PI L. Pentericci)

- $t_{int}$=10-20 hours
- CANDELS fields (GOODS-S COSMOS UDS)
- FORS2 observations cover the Lya visibility in the range 5.8<z<7.3
- Target selection based on  LBG color diagrams  and CANDELS photometric redshifts
- Including ancillary programs (PI Fontana, Bunker) we analysed a total of 230 hours of FORS2@VLT observations

Aims

- Evolutions of the Ly$\alpha$ visibility over the epoch of the reionization -> constrian neutral hydrogen fraction as a function of redshift and luminosity
- Evolution of Ly$\alpha$ properties of galaxies vs other physical parameters
- Provide targets for ALMA

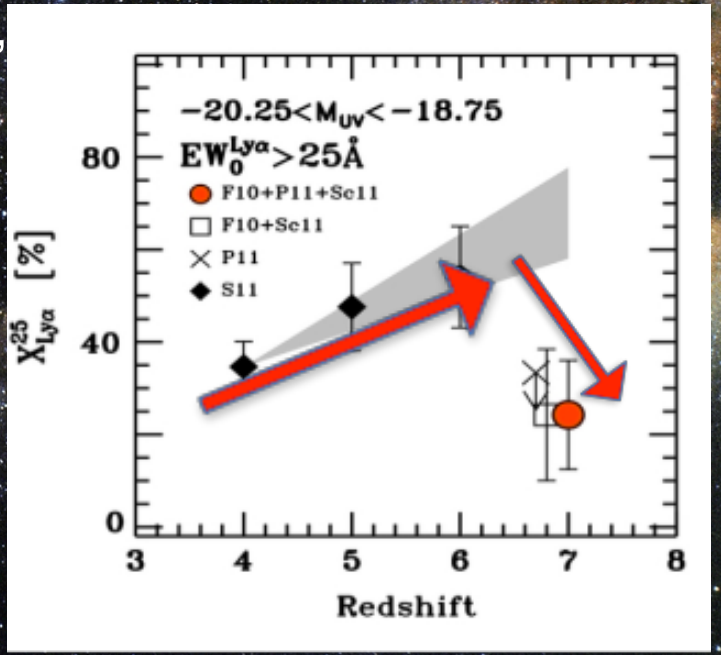
Results can be found in Pentericci et al. 2018, De Barros et al. 2017, Castellano et al. 2017

# Main motivation: when exactly does the Lyα decline?

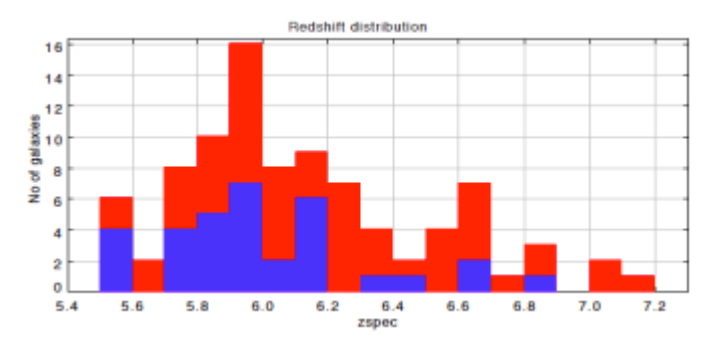
Early results by several independent groups indicated that the fraction is rising up to z=6 and then sharply declining (Stark+2010, +2011, +2014,Ono + 2012,Cassata+2012, Treu+2013, Caruana+ 2014 etc etc)

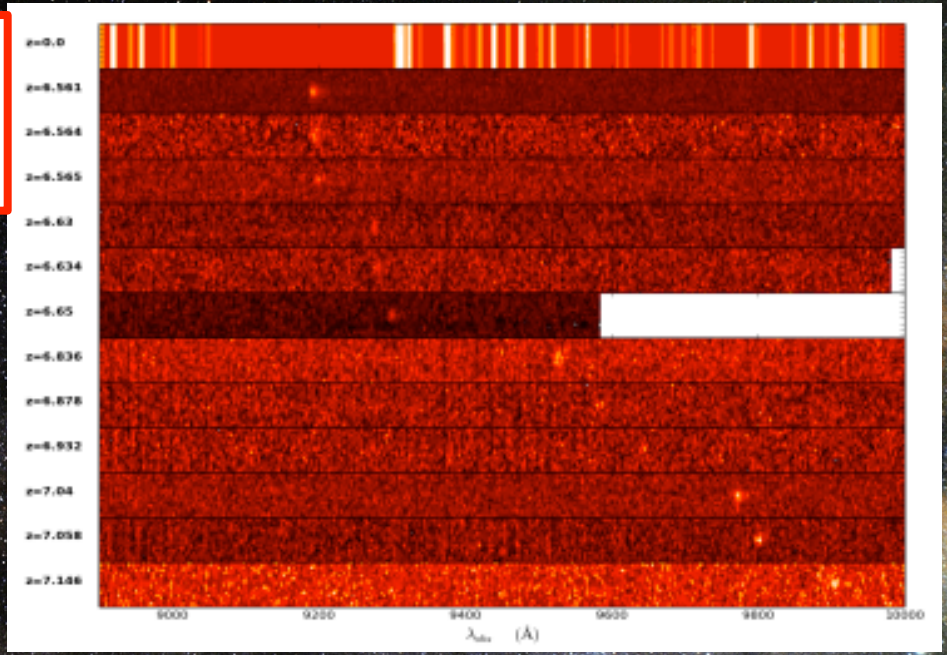
The rise and fall of Lyα is particularly pronounced for the faintest galaxies (but at these magnitudes samples are smaller and observations more difficult)

Field to field variation are large (patchy reionization LP+2014)



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

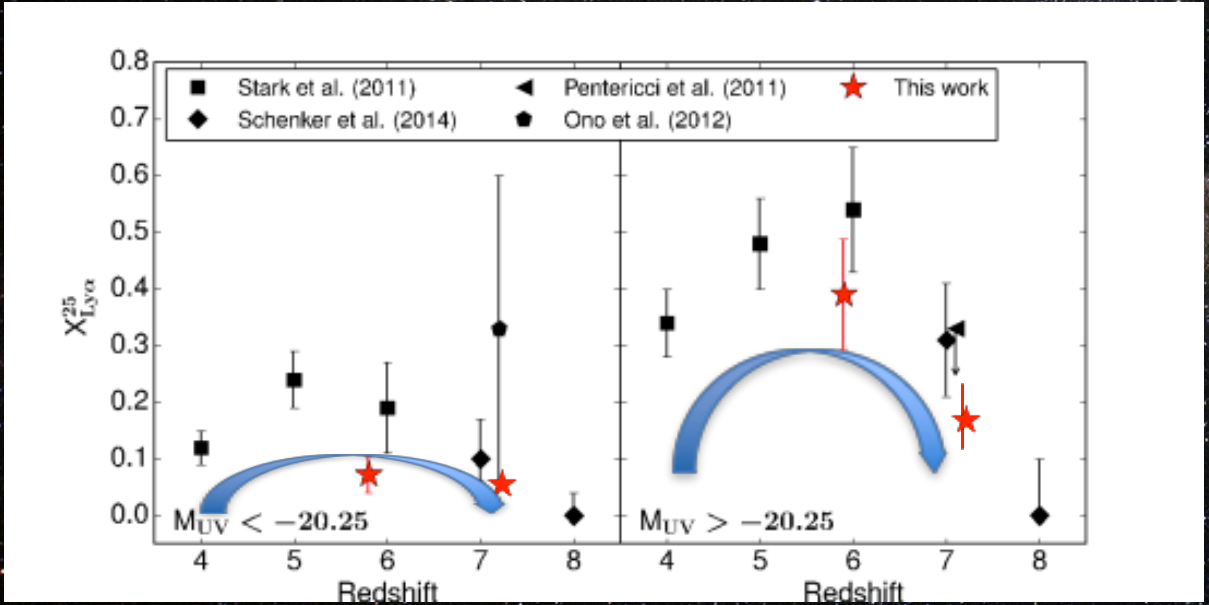



Including the new Large program data + earlier & archival observations (LP+2014,LP+2011,Vanzella+2011,2009, Caruana+2012,2014) we have assembled a sample of >135 z-dropouts & 130 i-dropouts in 8 independent fields (including 4 of the CANDELS fields), mostly observed with the same instrumental set-up 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)

# The Lyα decline begins at z<6

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




Pentericci+18, deBarros+17

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

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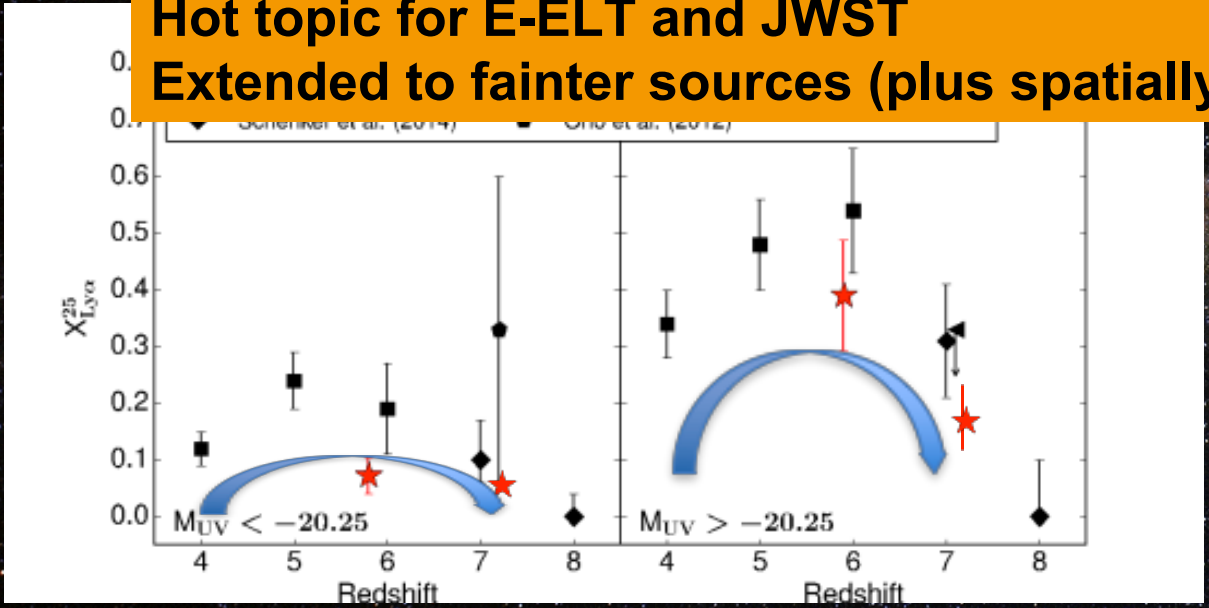
**Hot topic for E-ELT and JWST**
**Extended to fainter sources (plus spatially resolved emission)**

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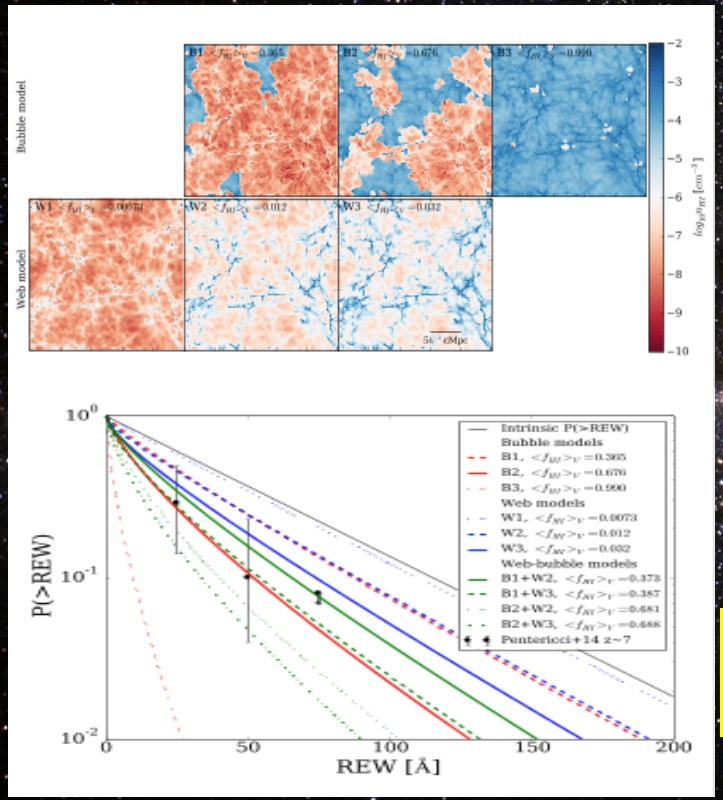
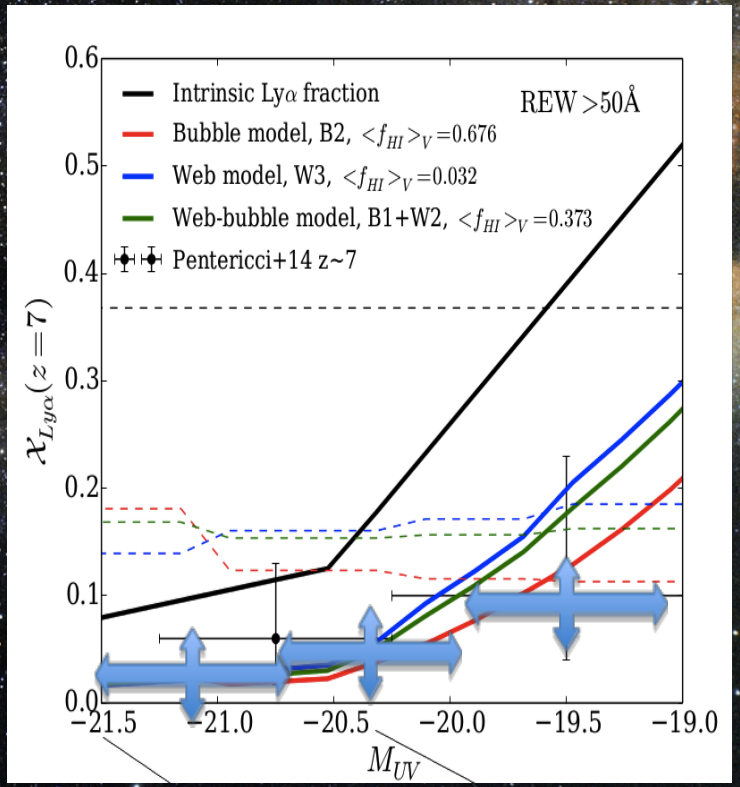
# Implications on the neutral hydrogen fraction

There are intrinsic degeneracies between the effects of small scales HI absorbers and diffuse neutral IGM. Kachiiki+2017 show that a joint anaysis of LAE LF and Lya fraction i LBGs can potentially discriminate between models.

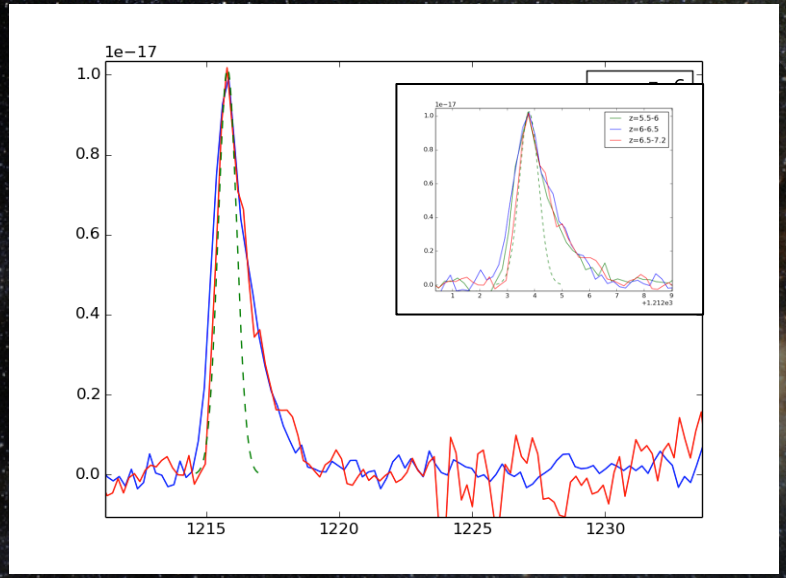



The new z=7 measurements favour slightly a bubble model with XHI=0.67



# First constraints on the effect of reionization on Lyα shape

Including previous data with FORS2 observations **taken with the same 600z grism** and using only high quality spectra we produced spectral stacks at z=7 (~20 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).
First time we see a change in the shape of Lyα!

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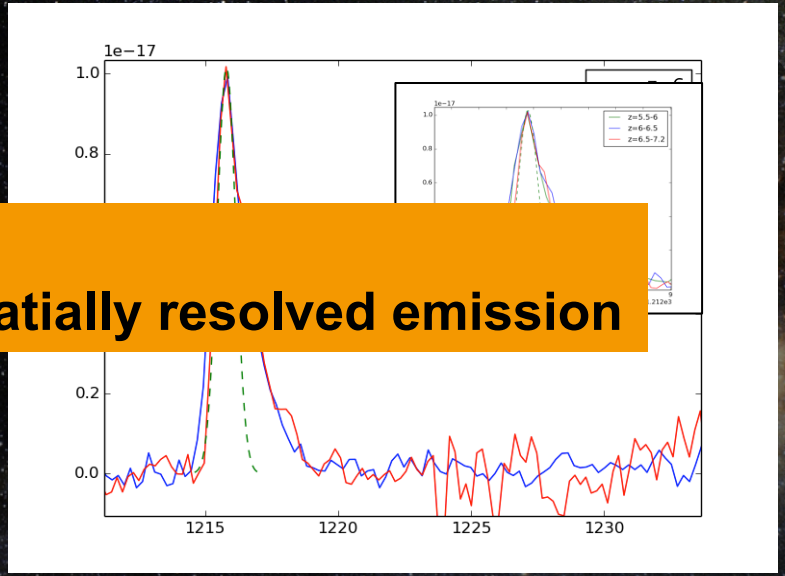
**Hot topic for E-ELT and JWST**
**High-resolution profiles, and spatially resolved emission**

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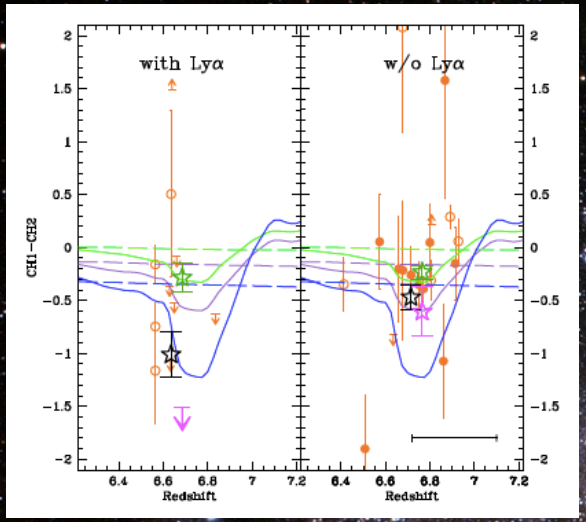
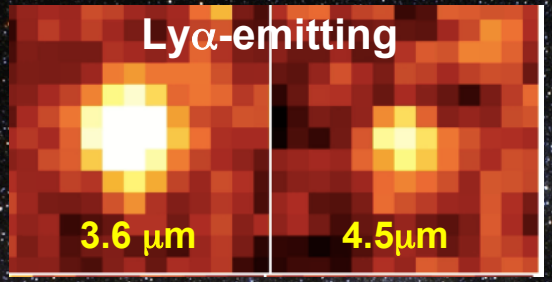
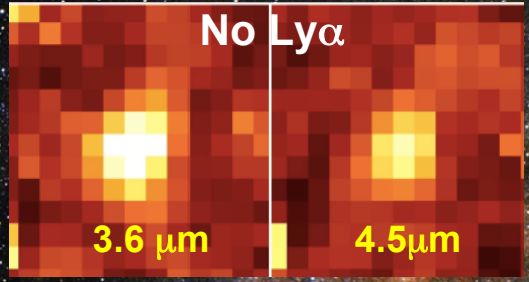
# Constraints on physical properties and LyC escape

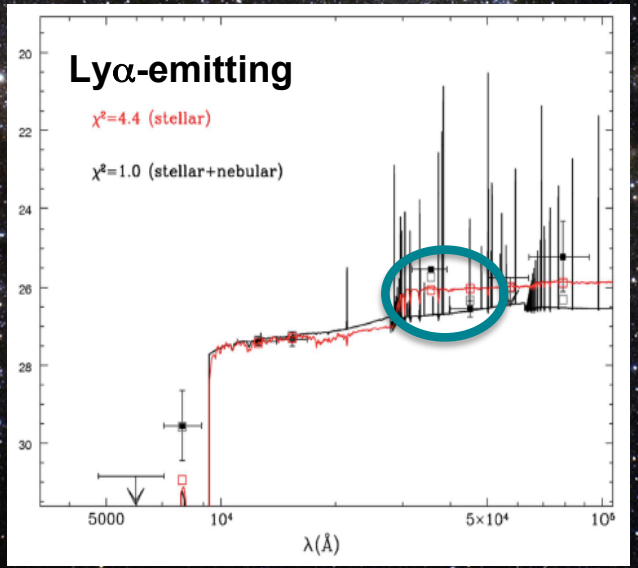


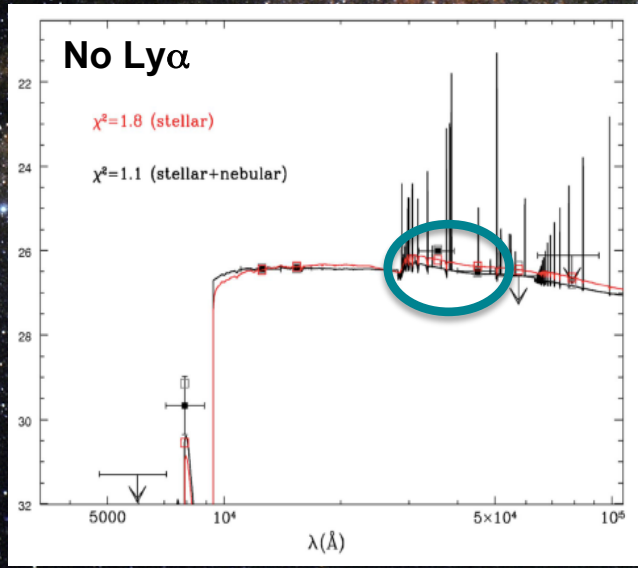

**IRAC color at z~6.6-6.9 is strongly affected by strength of optical lines**

EW([OIII]+Hb) larger in Lya-emitting galaxies (1000AA vs 500AA)
Such strong line emission implies fesc < 20% (50% under extreme assumptions) in Lya-emitting galaxies




Castellano et al. 2017 ApJ

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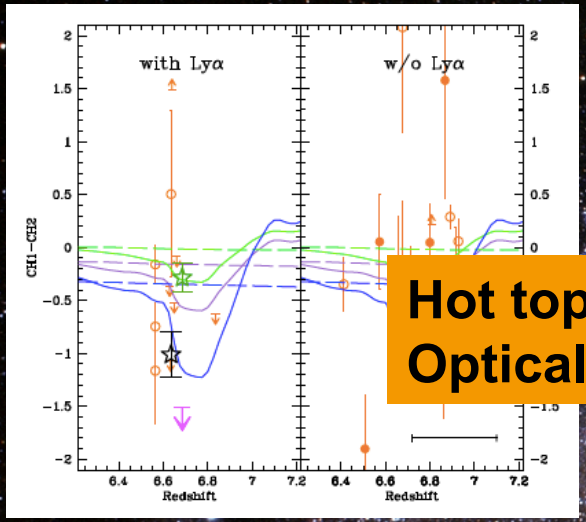


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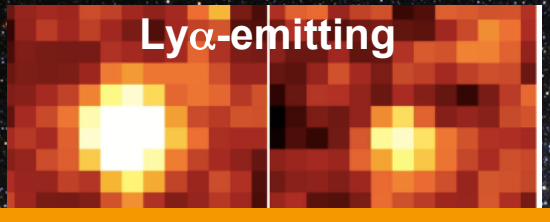
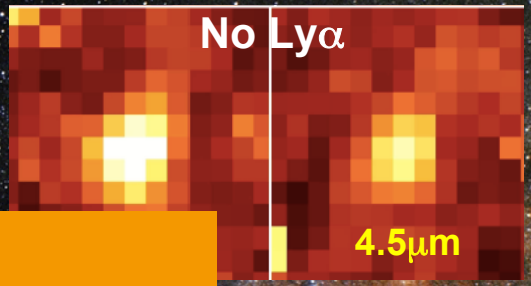
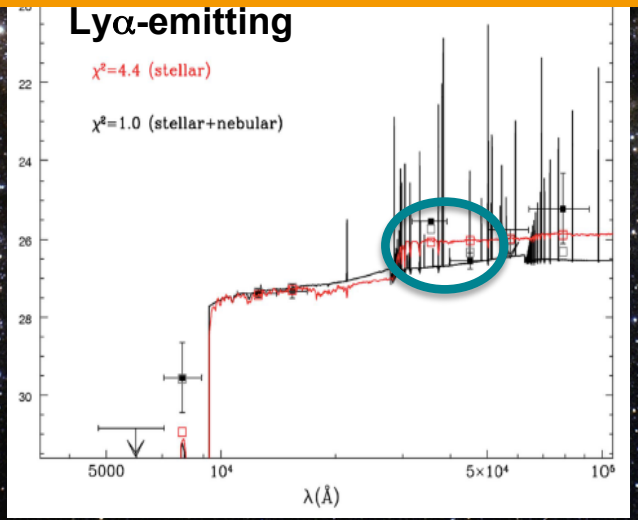
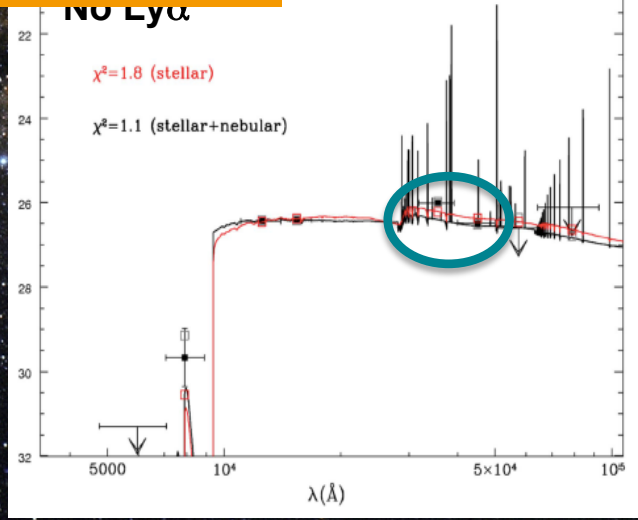


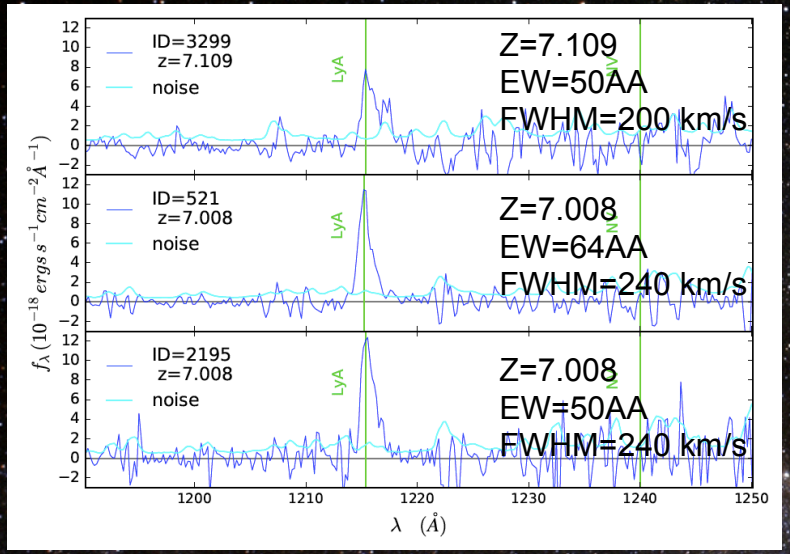

**Hot topic for JWST**
**Optical emission lines at very high redshift**

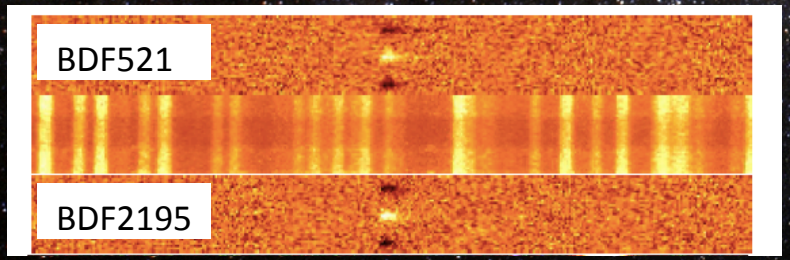


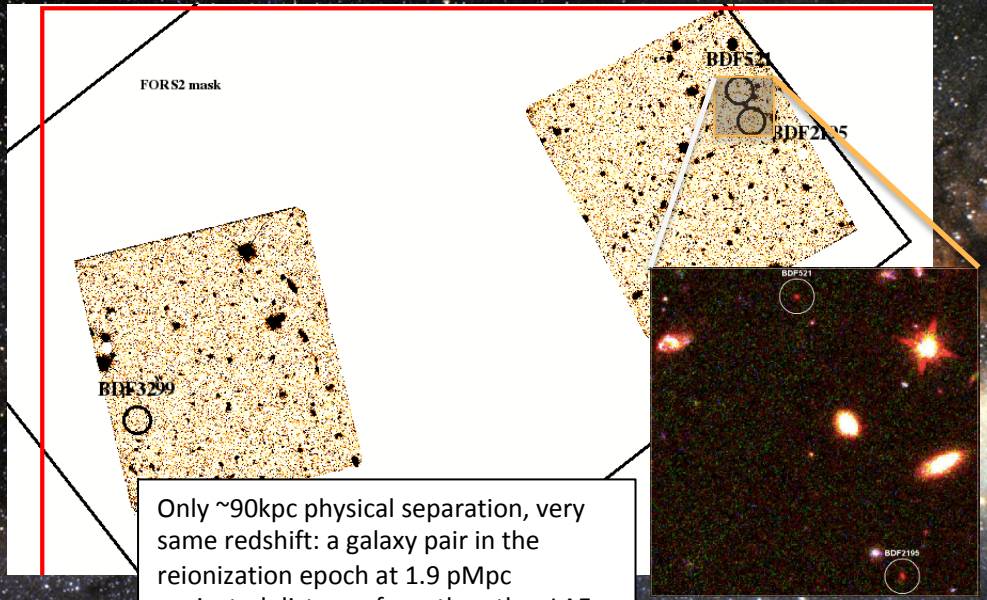

Castellano et al. 2017 ApJ

# Evidence of a reionized bubble with high Lyα visibility




Castellano et al. 2016 ApJL, 2018 ApJL




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

- Overdense region (3-4x average LF at z~7).
- Lyα fraction much higher than average at z~7: patchy scenario (see Pentericci+14) likely due to clustering.
- But puzzling lack of Lyα from faint companions.

MC+ ApJL, 2018

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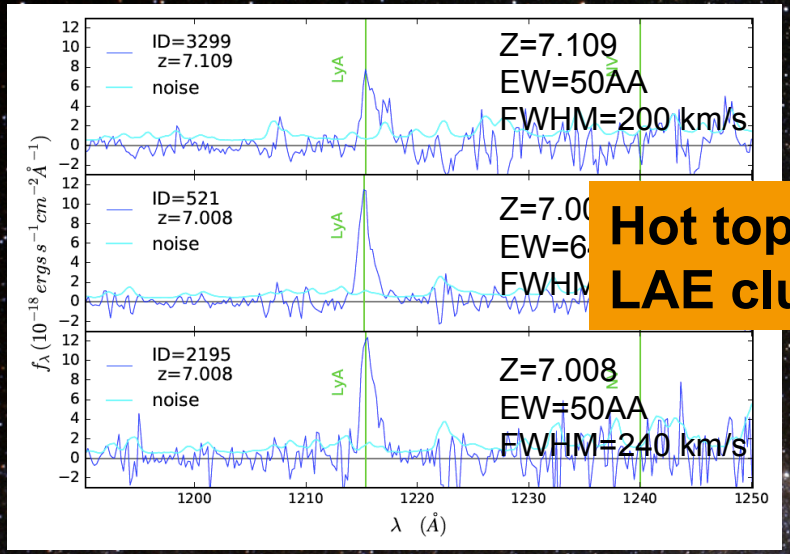


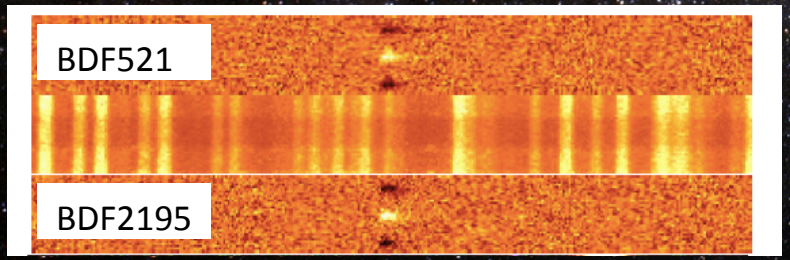


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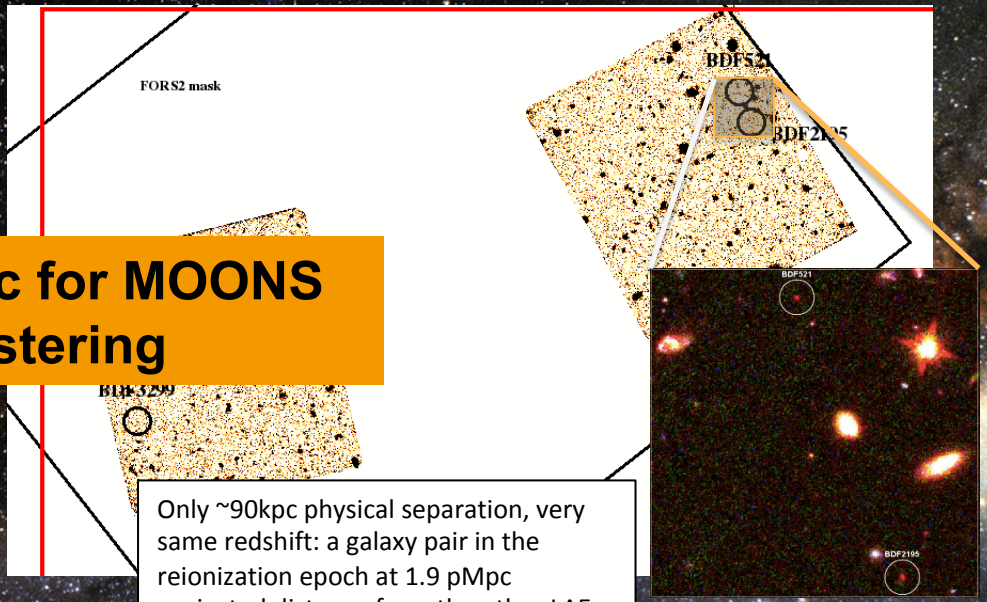


**Hot topic for MOONS**
**LAE clustering**

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MC+ ApJL, 2018

# Summary and conclusions

- Candelsz7 (LP 190.A-0685, PI L. Pentericci): a deep survey of galaxies at z~6-7 with VLT-FORS2.
- Final sample from Candelsz7 and archival observations: 135 z~7 and 130 z~6 LBGs in 8 independent fields (including 4 of the CANDELS fields).
- The rise in the fraction of Ly$\alpha$ emitters might actually stop at z > 5 with a flattening (for faint sources) or downturn (for bright sources) already at z=6.
- Consistent with a bubble model with 67% neutral IGM at z~7.
- First evidence of evolution in Ly$\alpha$ shape: blue side erased from z~6 to z~7.
- Analysis of physical properties as a function of Ly$\alpha$ emission: stronger EW([OIII]+Hb) for Lya-emitting galaxies.
- First evidence of a reionized bubble: enhanced Ly$\alpha$ visibility in a overdense region.