CANDELSz7: Looking for the CANDELS that reionized the

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in collaboration with
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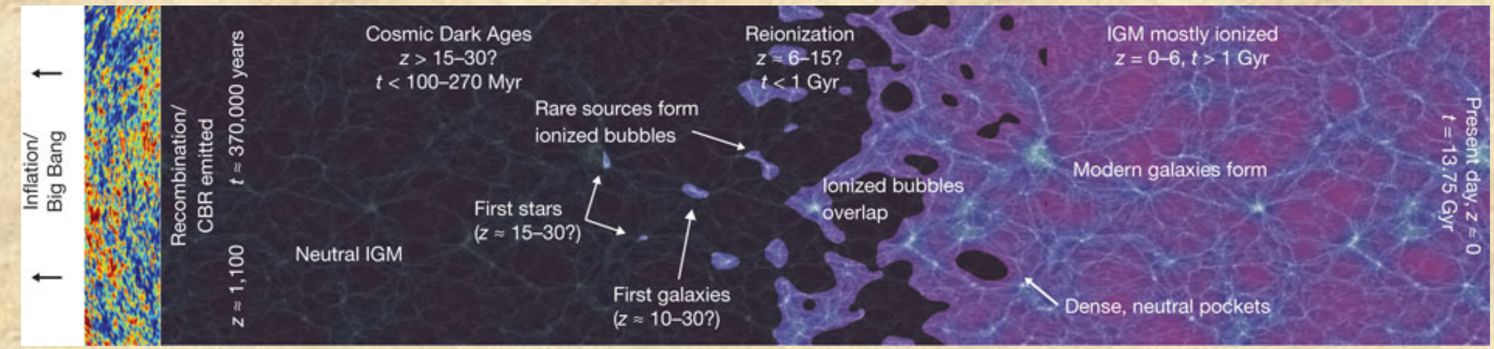
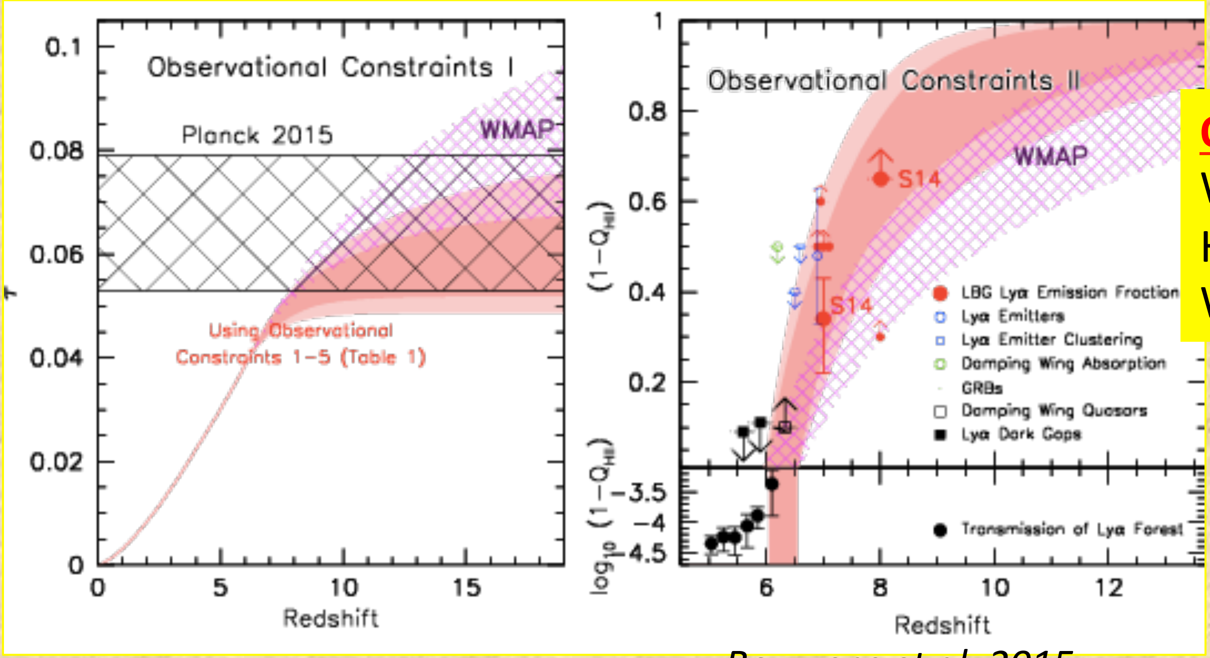
Raimbows on the Southern Sky, ESO 6th of October 2015

HI reionization epoch



Star forming galaxies & AGN form bubbles of ionized hydrogen that grow and eventually overlap. At the end of this process the Universe is completely ionized again.



Open questions:

When? Δz ??

How? $d[Q_{HII}]/dt$??

Who? Ionizing sources?

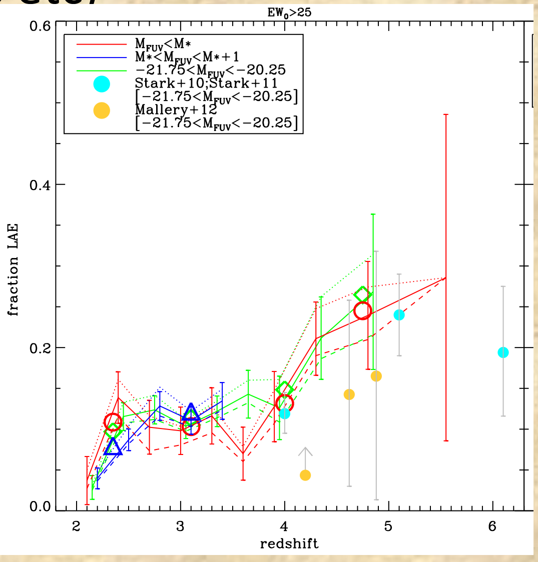
Bouwens et al. 2015

Latest constraints coming from Planck results compared to observational inferences from : Lyα emission fraction, LAE clustering, LAE LF, Damping Wing QSOs, GRBs, Lyα Dark Gaps etc

Probing the reionization epoch with Lyman Break galaxies and Lyα emission

RATIONALE - The Lyα emission should be present in all young star forming galaxies: it is quenched mainly by dust within the galaxies (although the final transmission is due also to the escape fraction, outflows etc)

As we go to higher redshift we observe a steady increase of the fraction of Lyα emission amongst LBGs (from z≈2 to z≈6) : this is an indication that galaxies become on average younger and less dusty hence they have stronger Lyα (*Cassata et al. 2014, Stark et al. 2010, Vanzella et al. 2009; Stanway et al. 2009*)

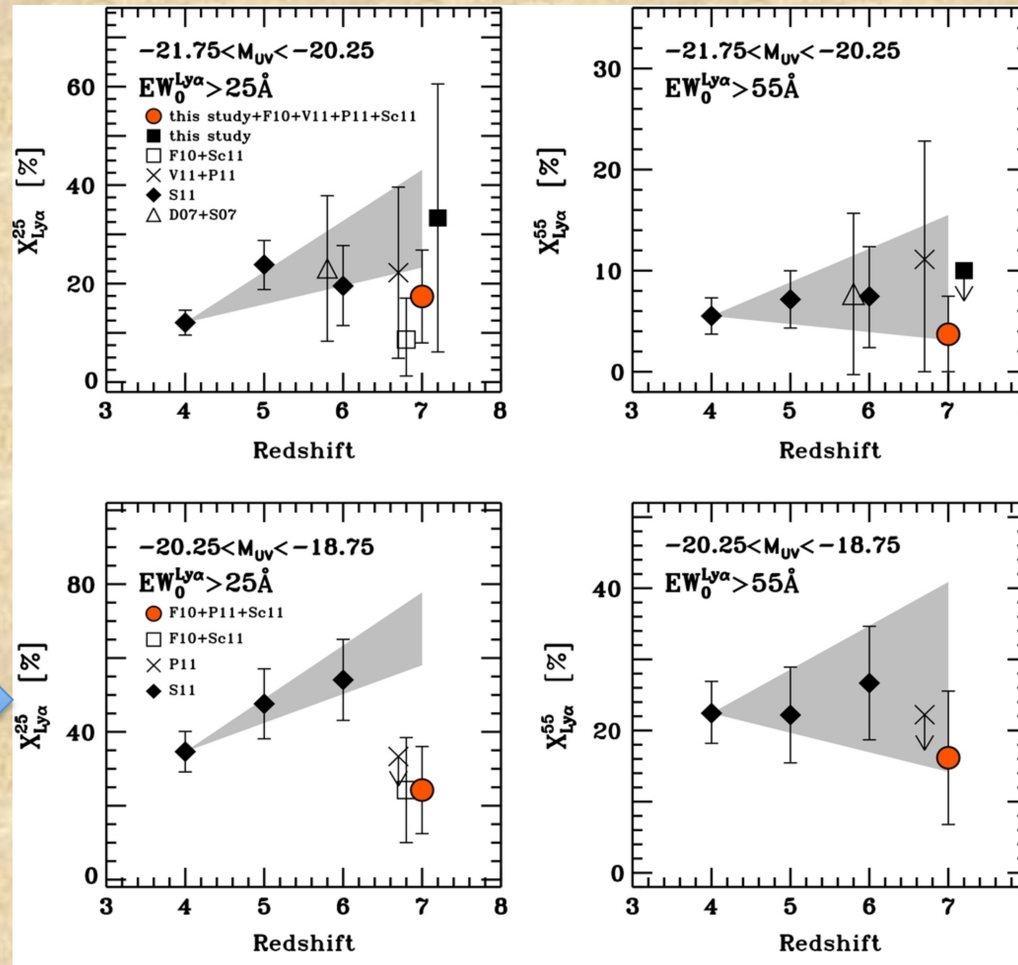


Cassata et al. 2014 (VUDS data)

As we probe earlier epochs, we should get to a point where the Universe becomes partly neutral: since the Lyα line is easily suppressed by even a small amount of neutral hydrogen *we expect to detect a lack of Lyα emission is star forming galaxies* provided that the galaxies properties do not change significantly over the same time interval

When does the Ly α decline? Early results (Fontana et al. 2010, Stark et al. 2010, LP et al.2011, Ono et al. 2012) by several independent groups indicated that at z≈7 the fraction of Lyα emission in LBGs is considerably lower than at ≈ z 6

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

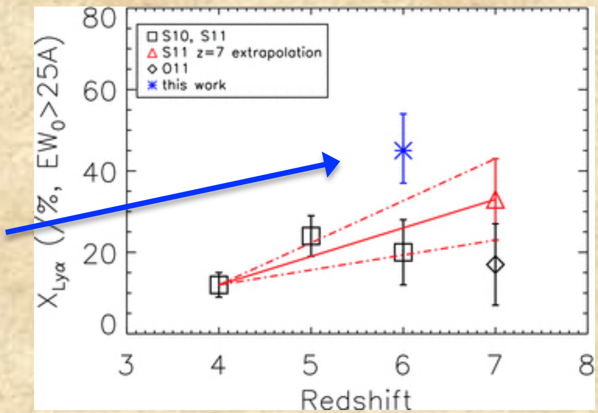


Stark et al. 2010, Pentericci et al. 2011, Ono et al. 2012 Schenker et al. 2012

CANDELSz7 : an ESO Large Program to probe the reionization epoch

Motivation

A.The early samples were **still small** and **very heterogeneous** in terms of : 1 selection (color vs zphot) 2. observational set-up (i.e. redshift coverage) 3. Lyα EW limit reached (not all spectroscopic data are deep enough)



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

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

To overcome these problems we designed CANDELSz7 an ESO Large Program with FORS2 to observe 200 galaxies at 5.5 < z < 7.3 in COSMOS/UDS/GOODS-S selected from the CANDELS official catalogs to determine a solid and unbiased statistics of Lyα fractions in this redshift range.

Selection of z ~ 6 & z ~ 7 candidates :

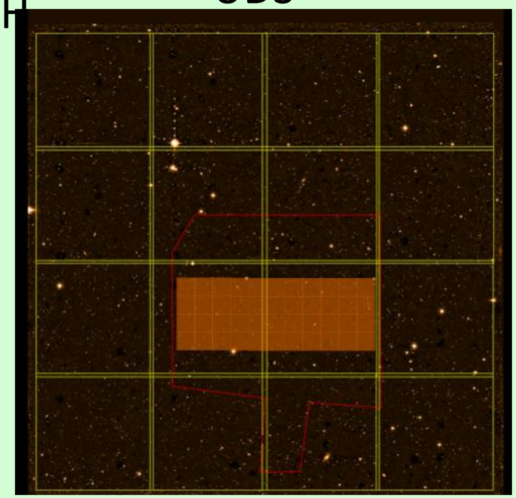
CANDELS: Cosmic Assembly Near-IR Deep Extragalactic Legacy Survey
PI S. Faber/H. Ferguson

902 prime orbits using WFC3 and ACS + parallel orbits

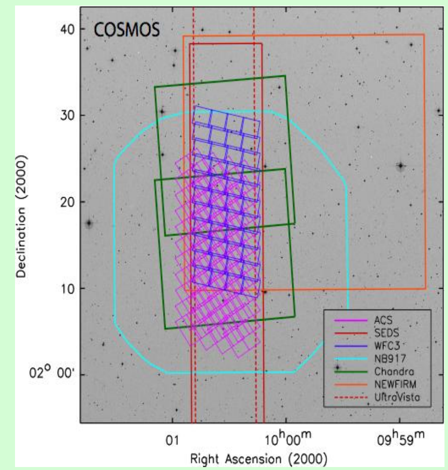
5 fields: GOODS-N/GOODS-S/UDS/COSMOS/EGS

GOODS-SOUTH

UDS



COSMOS



-Galaxies are selected with homogenous color-color criteria from the CANDELS data :

-The selection band (CANDELS H-band) is independent of the presence of Lyα at z =6 AND z=7 unlike past surveys and minimizes the bias

-We employ a unique spectroscopic set up and observational strategy: total integration time varies from 15 (for bright targets) to 25 hours (for faint targets) **to reach a uniform EW limit for all galaxies**.

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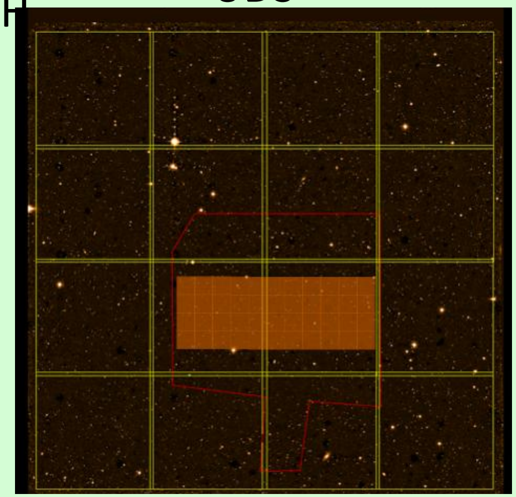

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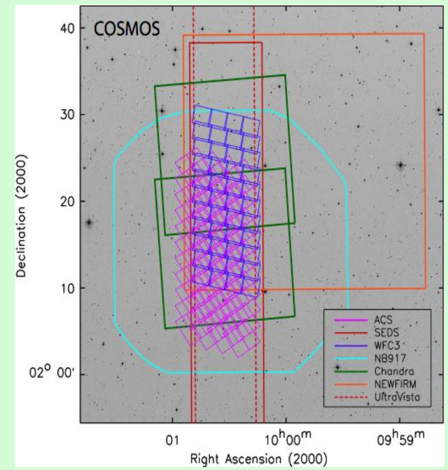

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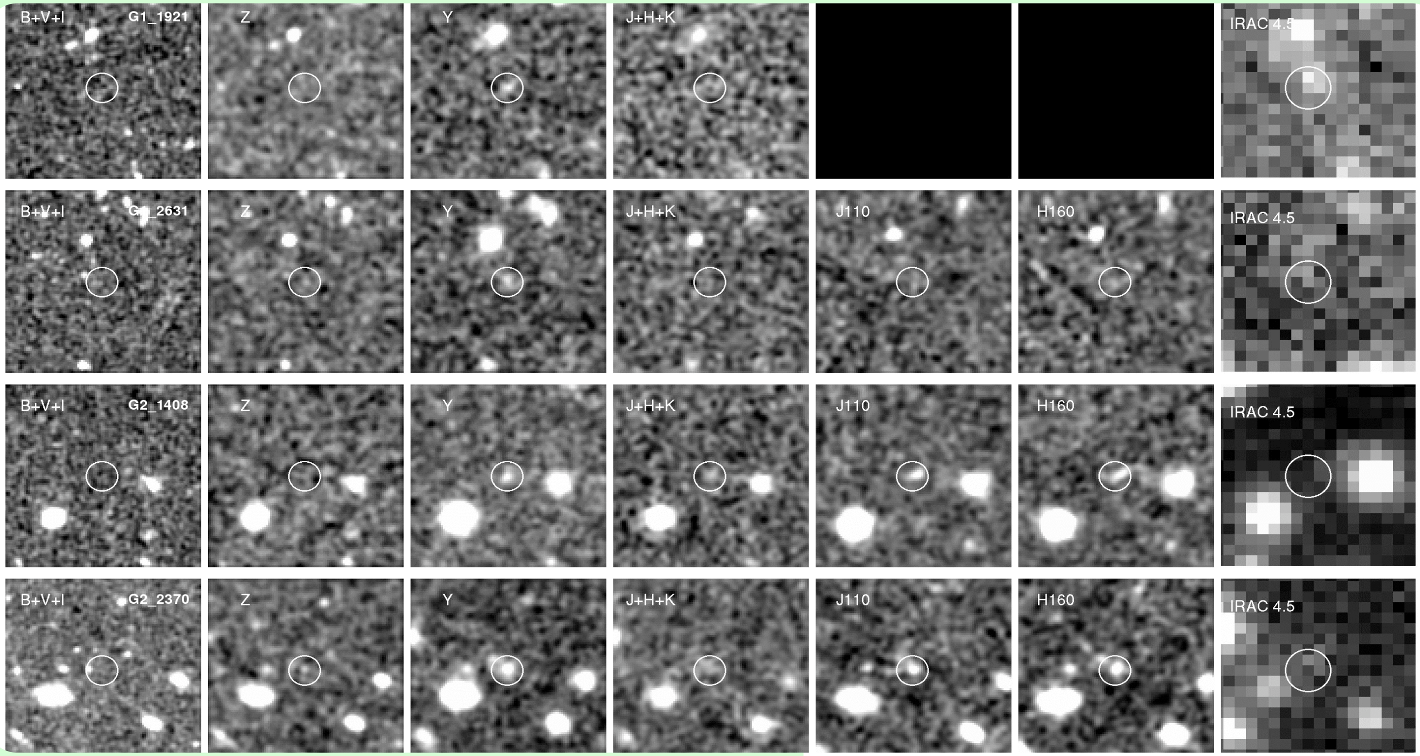
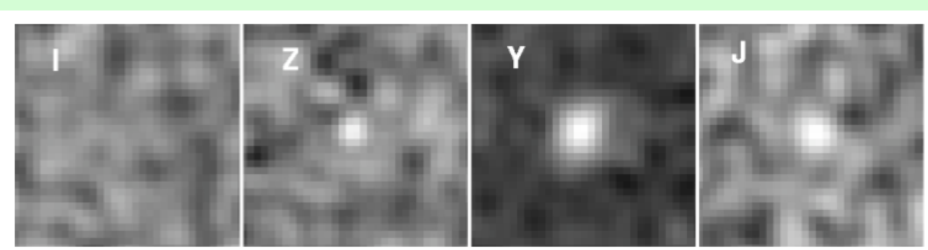
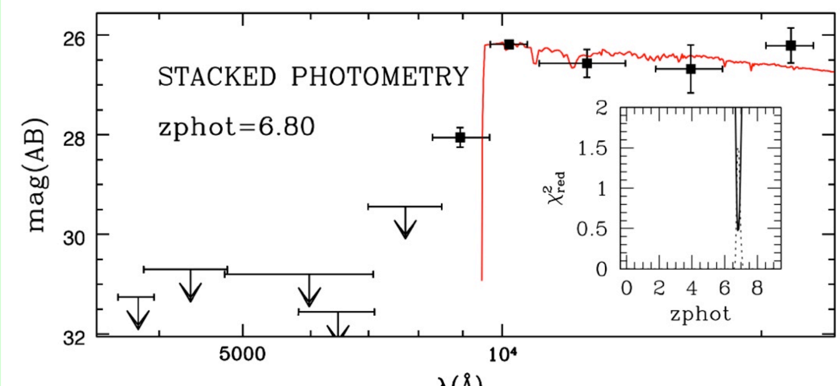
Examples of z=7 candidates in the GOODS-SOUTH field

B+V | Z | Y | J+H | J_{11} | H_{16} | 4.5μ



STACK OF ALL CANDIDATES





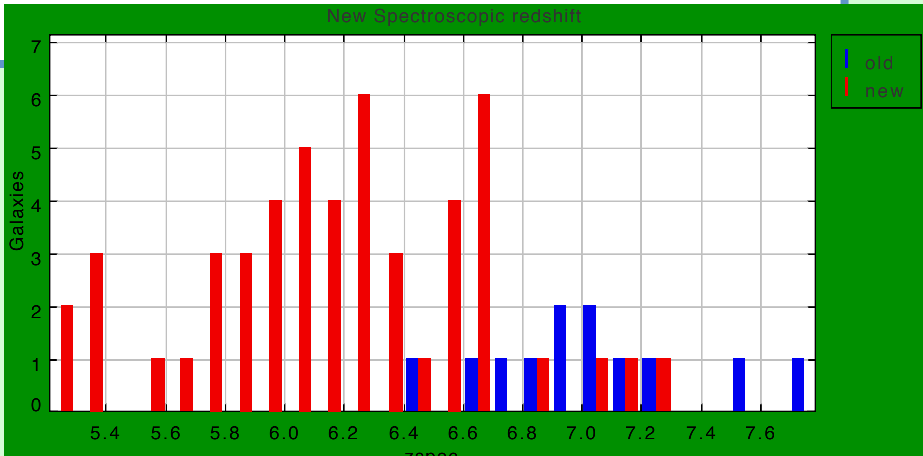
Very deep optical data are required to get rid of interlopers

STATUS OF CANDELSz7 AS OF 01/10/2015

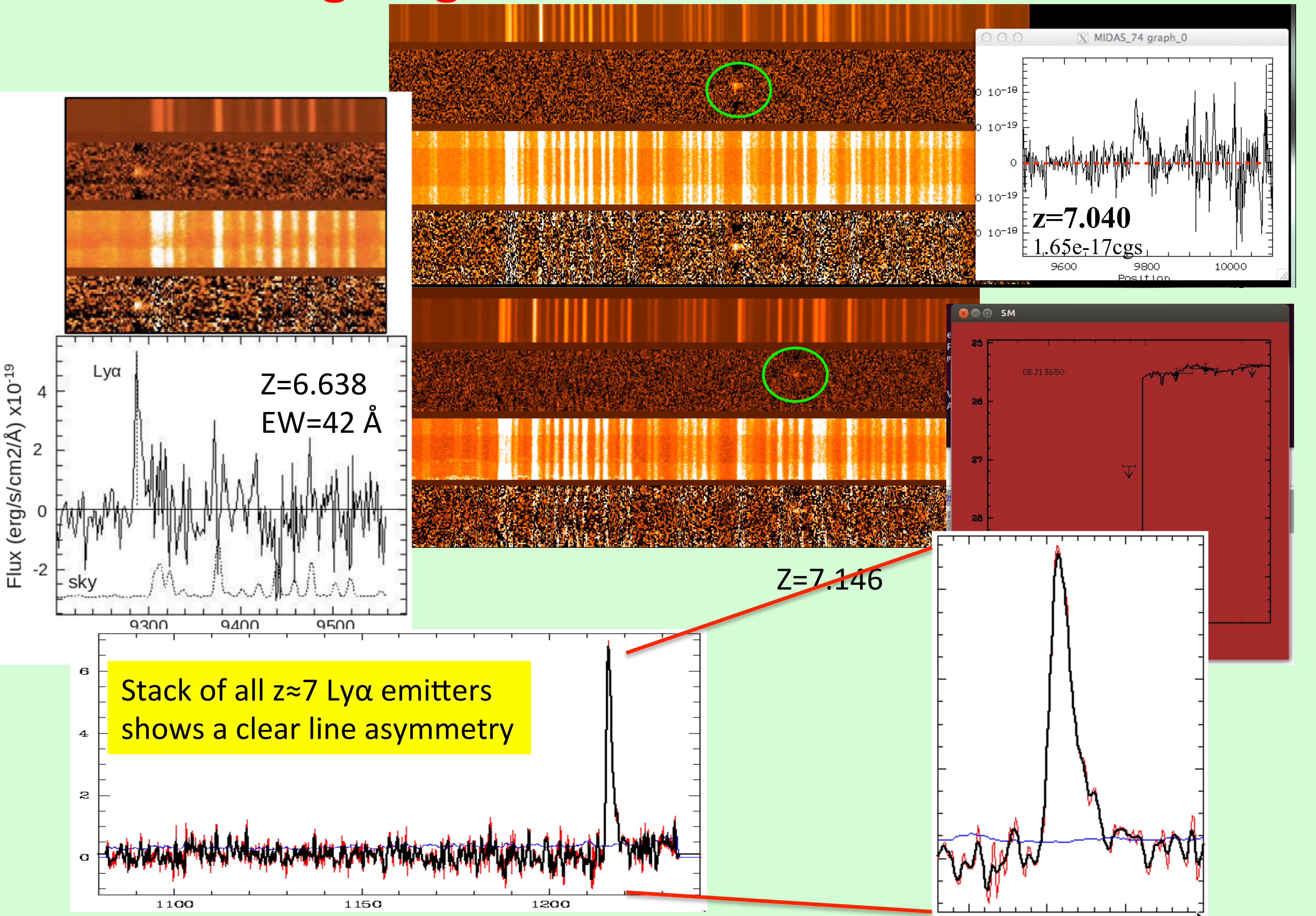
FIELD	TOT TIME	OBSERVED	REDUCED	ANALYSED
GOODS1	25	25	YES	YES
GOODS2	25	1	NO	
UDS1	15	15	YES	YES
UDS2	15	15	YES	YES
UDS3	15	2	NO	
COSMOS1	15	15	YES	YES
COSMOS2	15	15	YES	YES
COSMOS3	15	15	YES	PRELIM.
TOTAL	140 hours	103 hours		

So far we analised ≈55 new candidate z=7 galaxies observed in 3 independent fields (GOODS-S/UDS/COSMOS).
In addition a large number of i-dropouts observed and some high-z AGN and massive galaxies

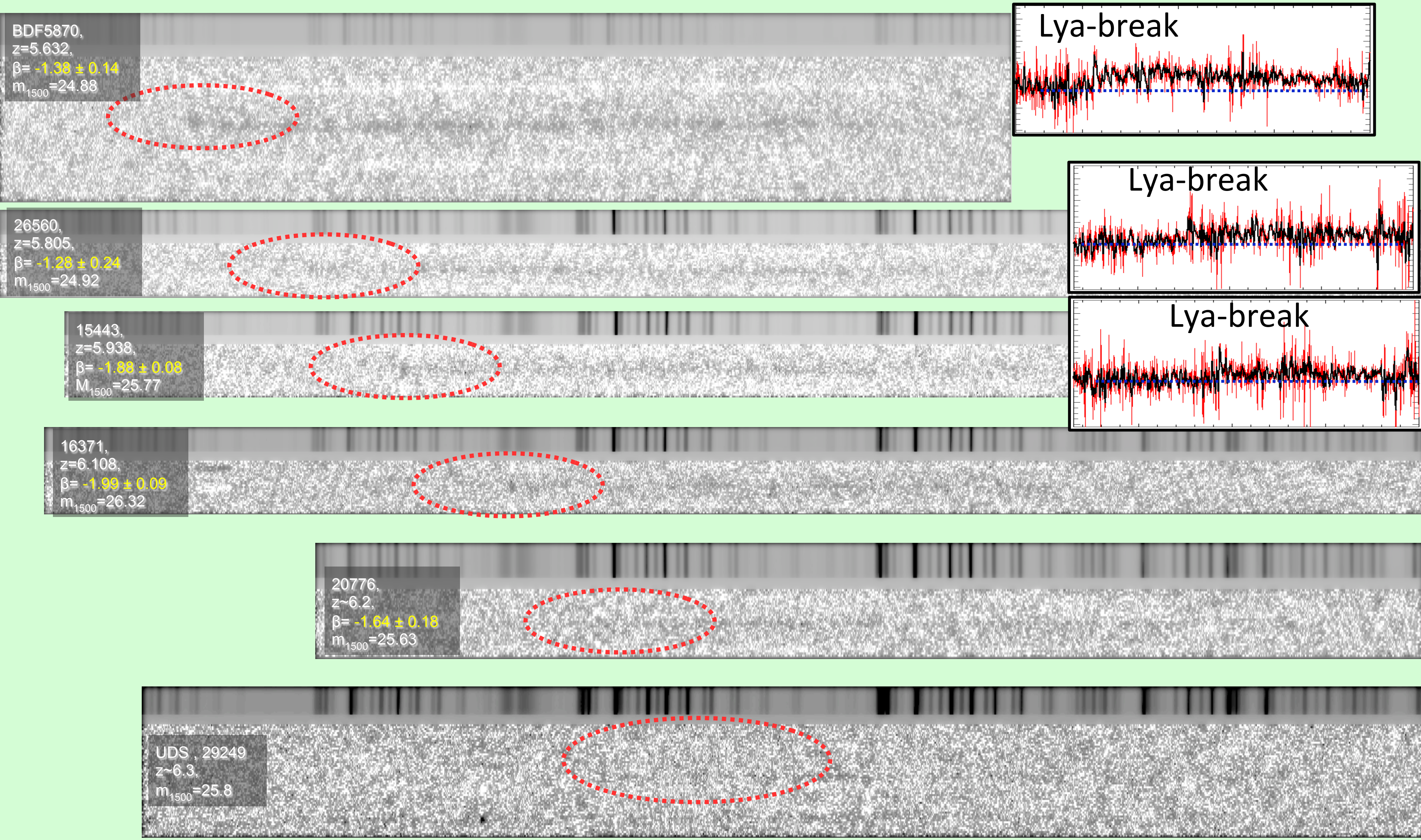
We have confirmed already 14 new galaxies at 6.5< z < 7.2 all with Lyα emission and ≈ 35 new 5.6<z<6.5 galaxies with Lyα plus several with no Lyα emission



Some new high-z galaxies in the COSMOS field

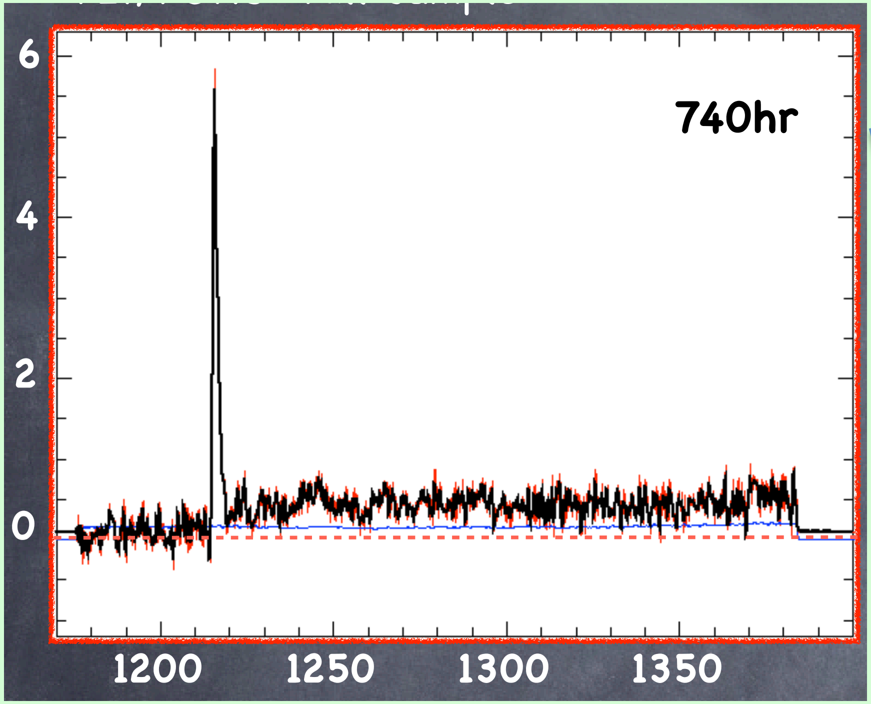


Deep spectroscopy starts to reveal faint z~6 non-Lyα emitters



Vanzella, Pentericci et al. in prep.

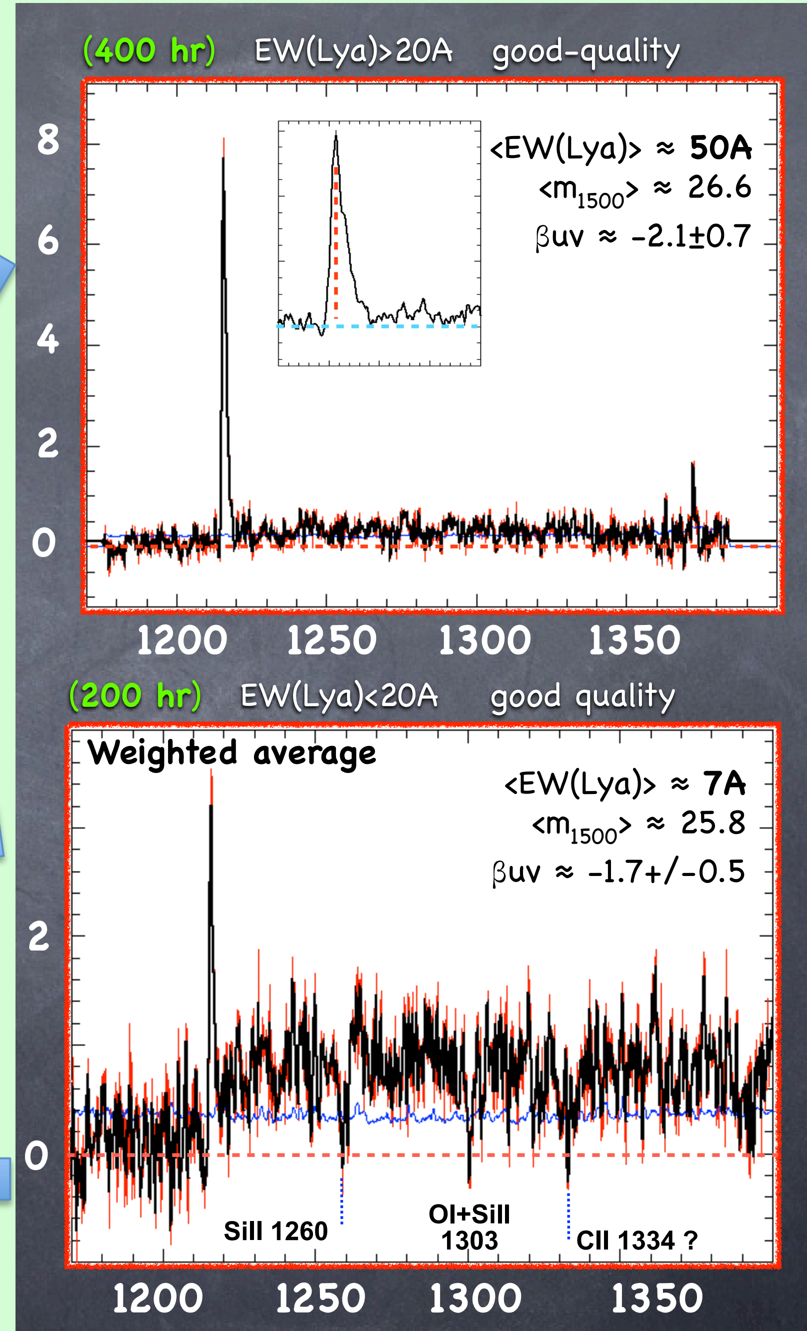
Deep stacking of z=6 galaxies



Compete sample: equivalent to 740 hours

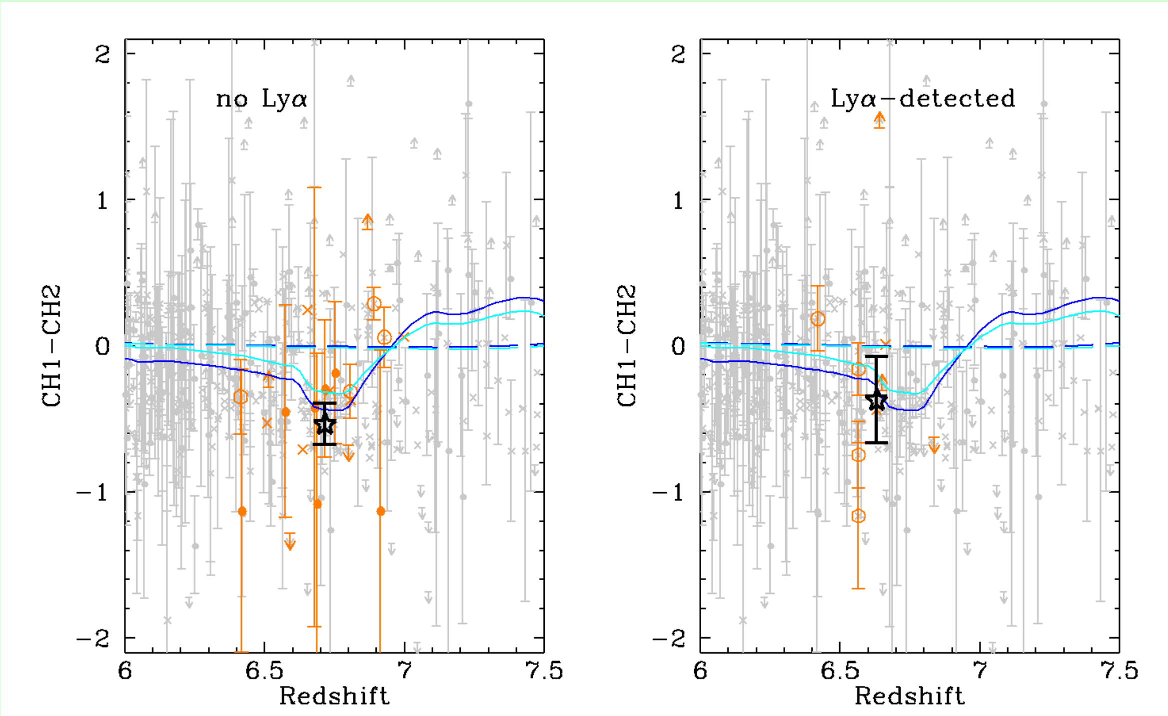
EW>20Å

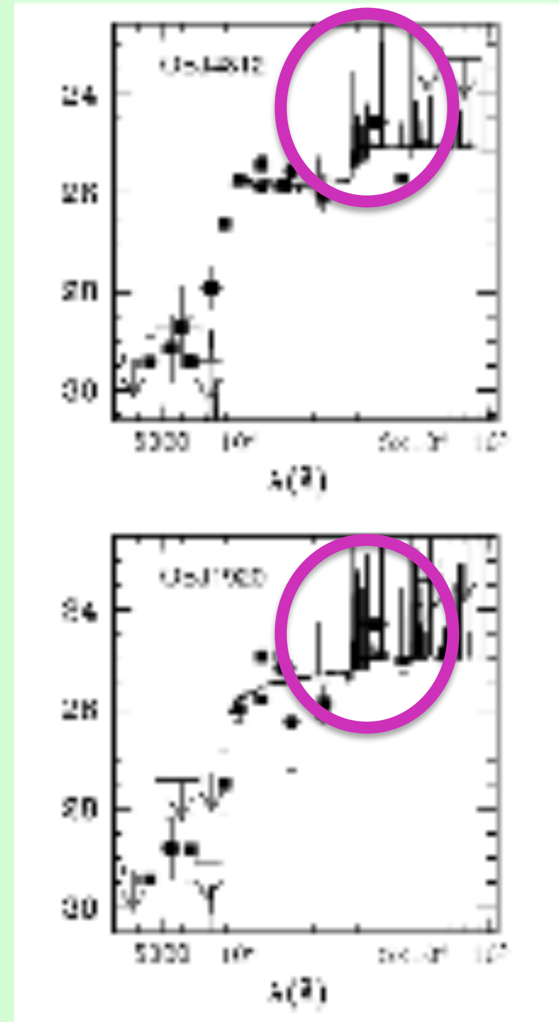
EW<20Å



Measure redshift for faint (mag=26) non LAEs
First time, non trivial
Half of the LBG population at z=6
Stacks allow us s to study properties (ISM abs lines , UV slopes, sizes) and trends

Evidence for nebular emission in z=7 galaxies





Stacking of targets in UDS and GOODS fields (where deepest IRAC imaging is available) with and without Lyα line

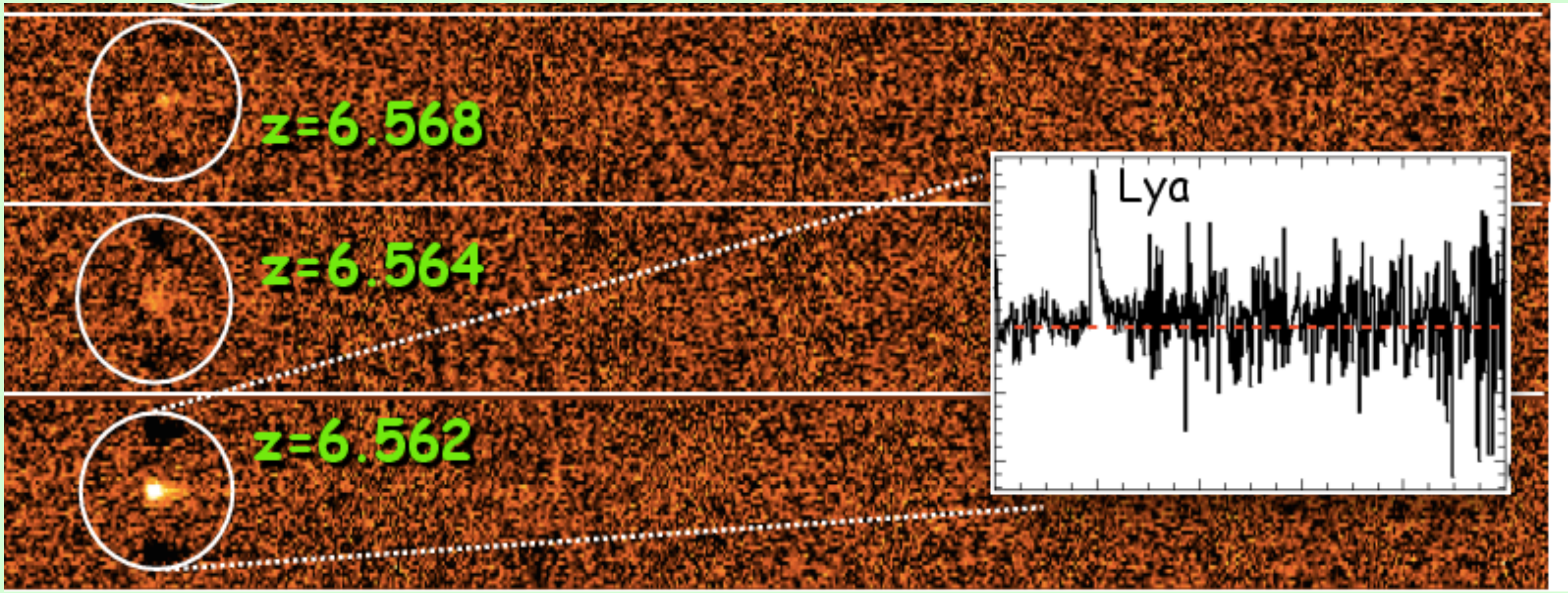
Ionization bounded nebula (Zackrisson et al. 2013) predict disappearing nebular emission as f_{esc} increases to 1
→ no evidence for this in our data

<EW([OIII]+Hβ)>~400-600AA, **not dependent on Lya visibility**.
Objects with EW up to > 1000 AA in both samples

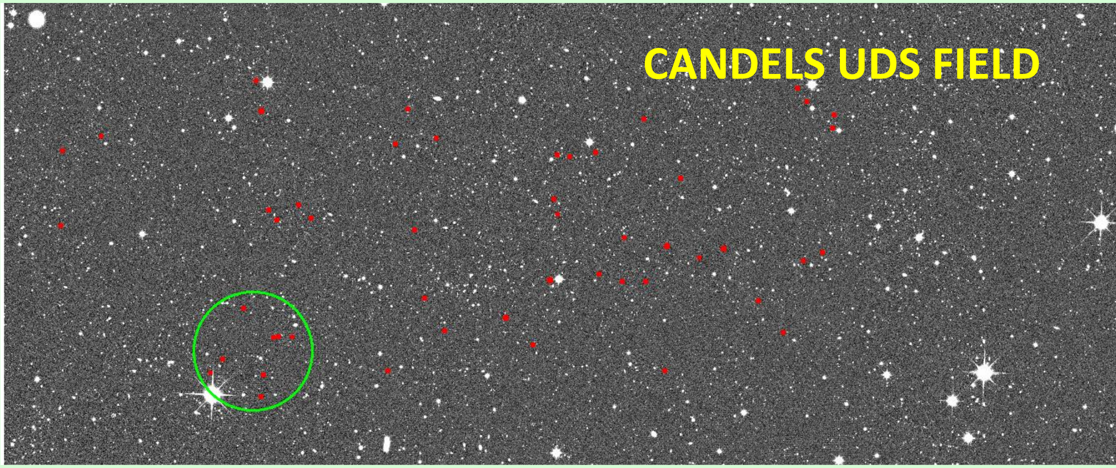
Castellano, Pentericci et al in preparation

Early structures in the reionization epoch: a triplet of galaxies at z=6.6 in the UDS field

We found three extremely bright galaxies (M_{UV}=-21-21.5) with Lyα emission line: redshifts are within 250 km/s of each other and sky positions within 1 arcmin (≈340 kpc proper) at z=6.56



The spatial distribution of all SF galaxies in the UDS CANDELS field with zphot=6.6±0.2 shows a > 6σ over-density around the triplet



The inhomogeneous distribution of neutral hydrogen during the reionization process results in significant fluctuations of Lyα transmissivity (e.g. Choudhury et al. 2014)

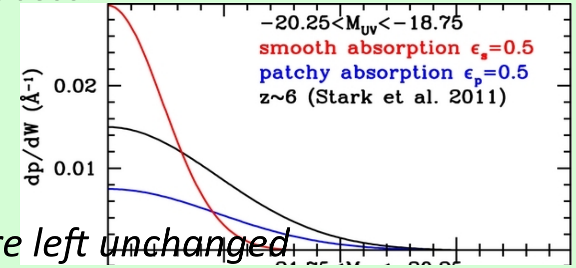
Pentericci et al. in preparation

Measuring the topology of reionzation

Treu et al. (2012) developed a simple model that can distinguish between a patchy and a homogenous reionization: the mean number of detections depend <u>both</u> on the average opacity of the IGM (the ε parameter) and on the patchiness of the reionization process:

*(1) **smooth reionization**: all emitters are quenched by the same average amount of neutral hydrogen , so the luminosity goes down homogeneously*

*(2) **patchy reionization** : some of the emitters are completely quenched by neutral hydrogen while others lie in ionized regions and are left unchanged*



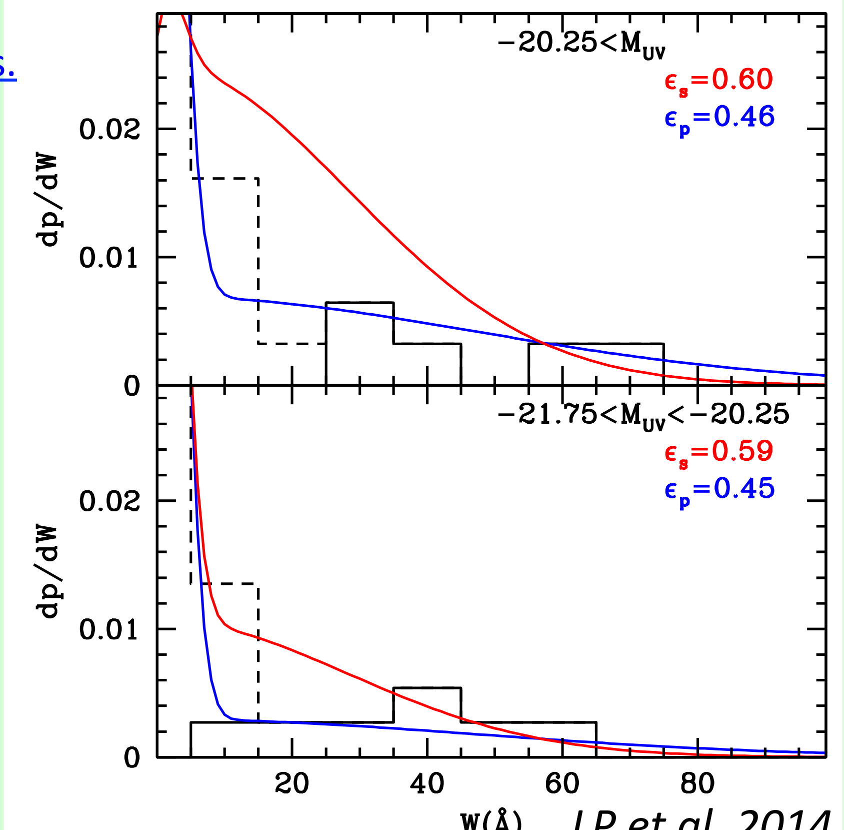
<u>Observing samples at different fluxes allow us to break the degeneracy between ε and the patchiness and hence measure the topology of the reionization process.</u>

Evidence ratio $\lg(Z_p/Z_s)=1.26$

↓

The patchy model is 18 times more favoured by the data compared to the smooth one; $\varepsilon_p = 0.45 \pm 0.11$

Final results from Large Program Sample… coming soon!!



LP et al. 2014

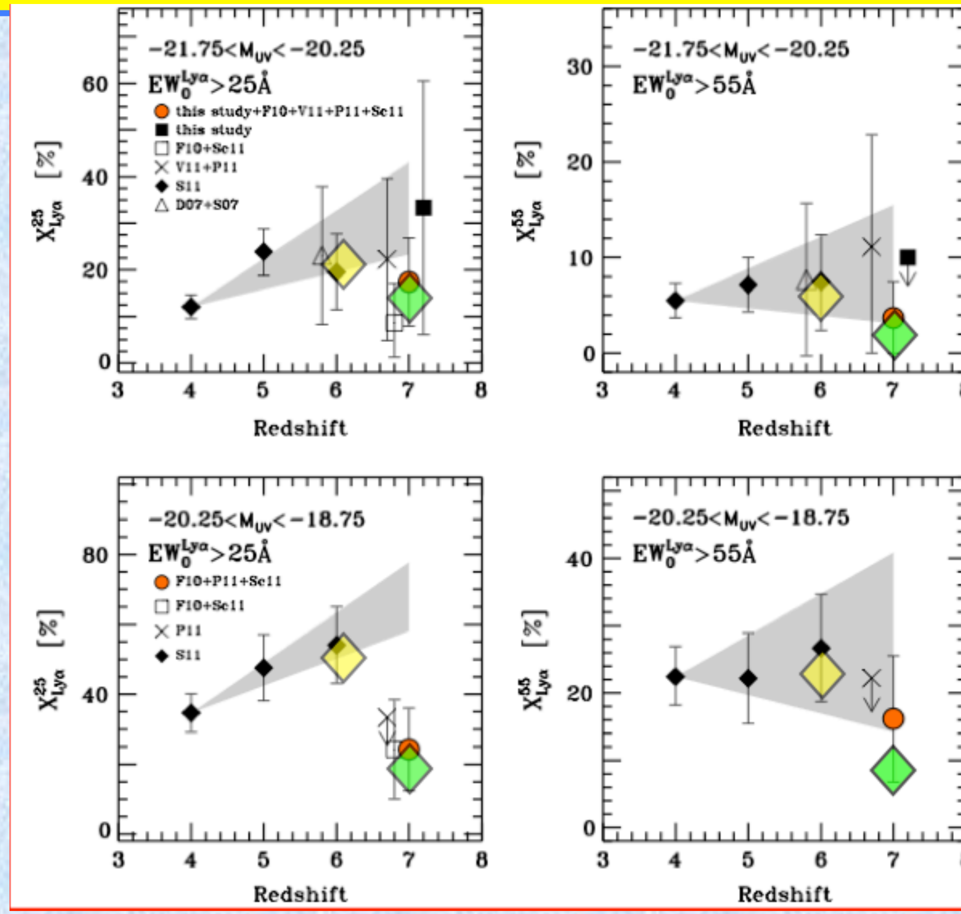
Including new Large Program data plus earlier and archival observations we have assembled a sample of ≈120 solid z-dropouts & 180 i-dropouts in 5 independent fields: this is the largest sample of high redshift galaxies observed spectroscopically. We can now measure the fraction of Lyα emission at z=6 and z=7 with great accuracy

Points at z=4,5,6 are derived from the large samples of Stark et al., Vanzella et al, Stanway et al. Shaded areas are the uncertainties.

new z=7 limits

new z=6 limits

limits Ono et al. 2012



bright galaxies (M_{UV}<-20.25)

faint galaxies (M_{UV}>-20.25)

EW(Lyα) > 25 Å   EW(Lyα) > 55 Å

What does it mean ?

☒ A significant fraction (> 60-70%) of targeted galaxies is not at z≈7; however

1. we do not detect any other line/feature in almost all cases
2. The LBG technique works very well at z=6 with <20% interlopers
3. stacked optical bands yield to upper limits of > 30 mags on Lyα undetected objects

☒ There is a sudden (< 200 Myrs) change in some of the galaxies physical properties → unlikely from theoretical predictions and observations
e.g. UV continuum slopes which do not change sensibly in this redshift range (e.g. Bouwens et al. 2014)

☑ There is an increase in the Lyman Continuum escape fraction (Dijkstra et al. 2014)

$L_{\alpha,obs} \propto N_{ion}(1-f_{esc})f_{esc}^{Ly\alpha}\, T_{IGM}$

☑ There is an increase in the amount of neutral hydrogen in the surrounding IGM that quenches the Lyα emission e,g. Mesinger et al. 2014

Is Lyα quenched by neutral hydrogen? Setting constraints on the neutral hydrogen fraction

We employ the models developed by **Dijkstra & Whyite (2011)** which couple large scale semi-numeric simulations of reionization with galaxies outflows, adpated to our redshift and mass range

Assumptions – the Universe is completely ionized by z=6
- the escape fraction of LyC photons remains unchanged
- the EW distribution at z=6 is modeled as an exponential function that matches the observations **TO BE UPDATED with new z≈6 results!!!!**
- the halos of simulated LBGs have $5 \times 10^{8} M_{\odot} < m_{halo} < 10^{12} M_{\odot}$ (this corresponds to SFR up to 1-20 $M_{\odot}$/yr as in Tren & Cen 2007)
- the galaxies have no dust both at z=6 and at z=7

Variables:

--Outflowing wind velocity

FIDUCIAL MODEL 200 km/s

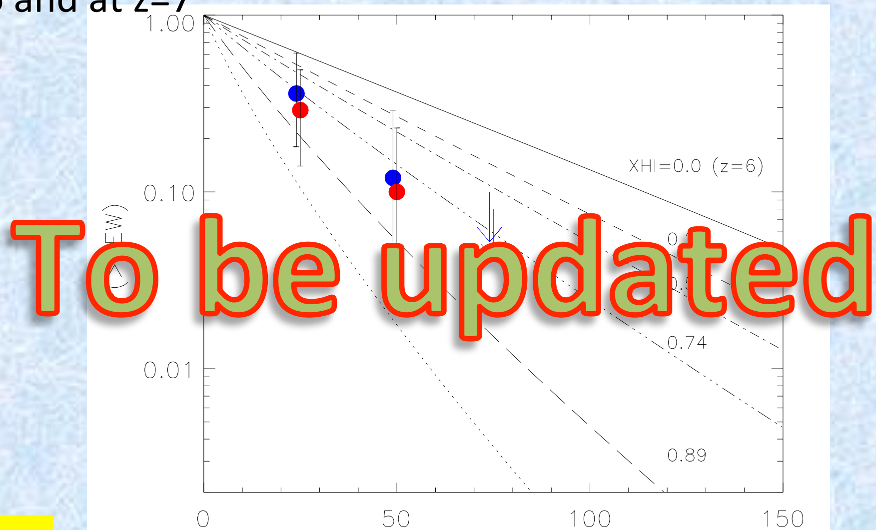
--Neutral hydrogen fraction

--Column density of HI

FIDUCIAL MODEL: $N_{HI}=10^{20}$ cm^{2}

● ● fractions assuming that 0-20% of the candidates are lower redshift interlopers

$X_{HI} \geq 0.5$ @z=7



Pentericci et al. 2014

Clearly the next step is exploring the z>> 7 range and determine the re-ionization timeline up to earlier epochs.. ...not a easy task!!

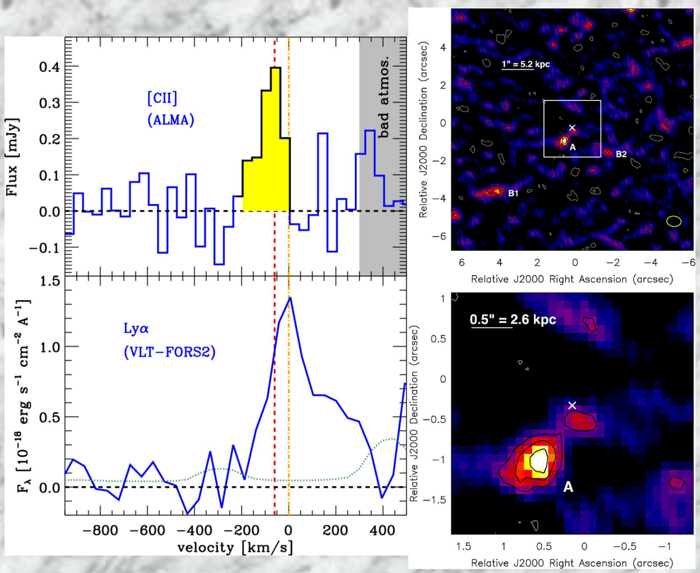
If the trend of decreasing Lyα is confirmed → galaxies at z > 7 might mostly have extremely faint Lyα emission lines (EW < 10 Å flux < 10^{-18} erg/s/cm) <u>or Lyα may be absent</u> → it will be hard to secure the redshifts of *statistical samples* of z=7.5-8.5 galaxies with current near-IR facilities (MOSFIRE, KMOS, LUCIFER..)

→ So far just 3 z=7.5-7.7 galaxies confirmed (Finkelstein et al. 2013, Oesch et al. 2015, Watson et al. 2015) despite the many attempts.

We have to seek new methods to confirm the redshift of sizeable samples of galaxies during the first 600 Mys

Solution (maybe) is ALMA: [CII]158μm line is not effected by neutral hydrogen & dust. In z≈7 galaxies observations have proved hard initially (Ota et al. 2014, Gonzalez-Lopez et al. 2014 Ouchi et al. 2013) but we are starting to get some results

(Maiolino et al. 2015, Watson et al. 2015)



[CII] in *BDF3299 z=7.108 (Maiolino et al. 2015)*