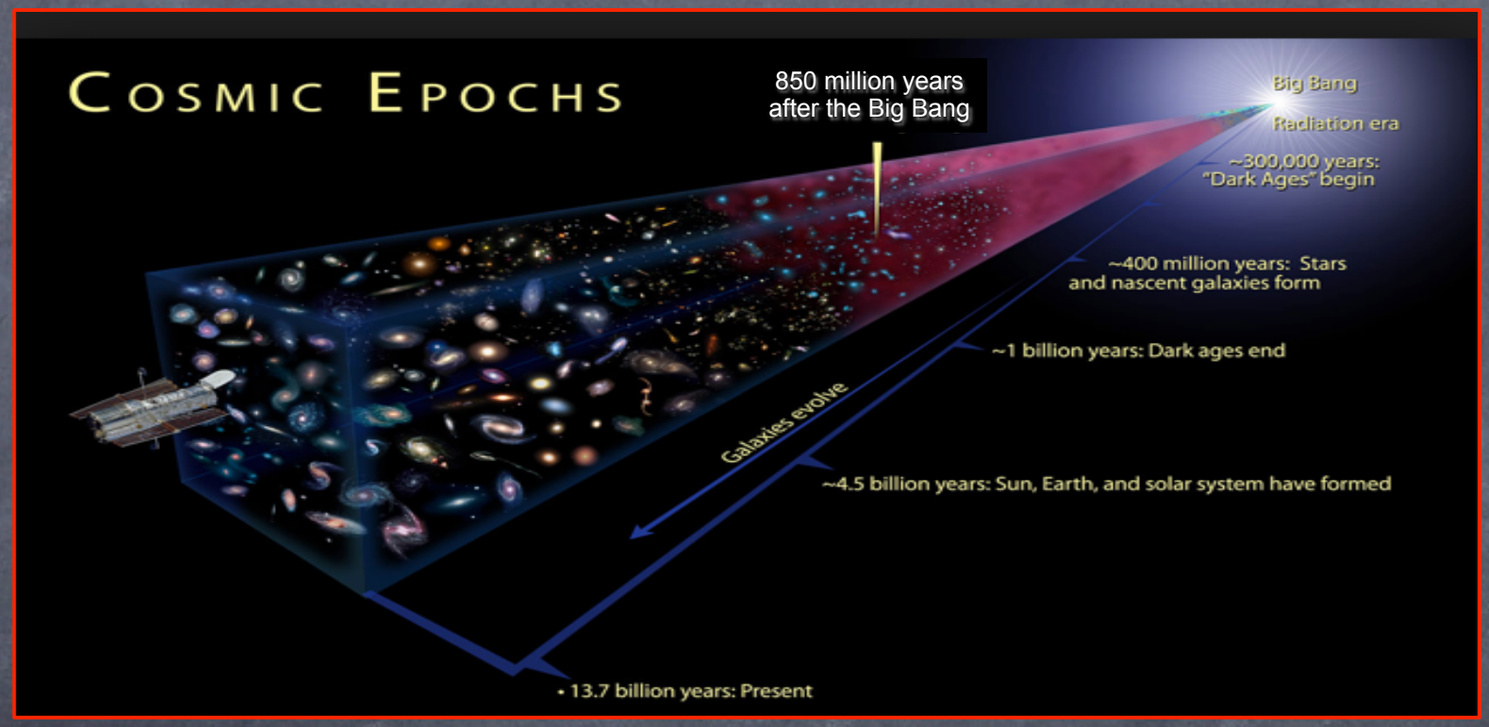
Investigating star-forming galaxies in the first billion years with deep spectroscopy

Eros Vanzella

INAF - Astronomical Observatory of Bologna



Collaborators:

L. Pentericci, A. Fontana, A. Grazian, M. Castellano, L. Guaita, S. De Barros, M. Giavalisco, G. Zamorani, C. Vignali

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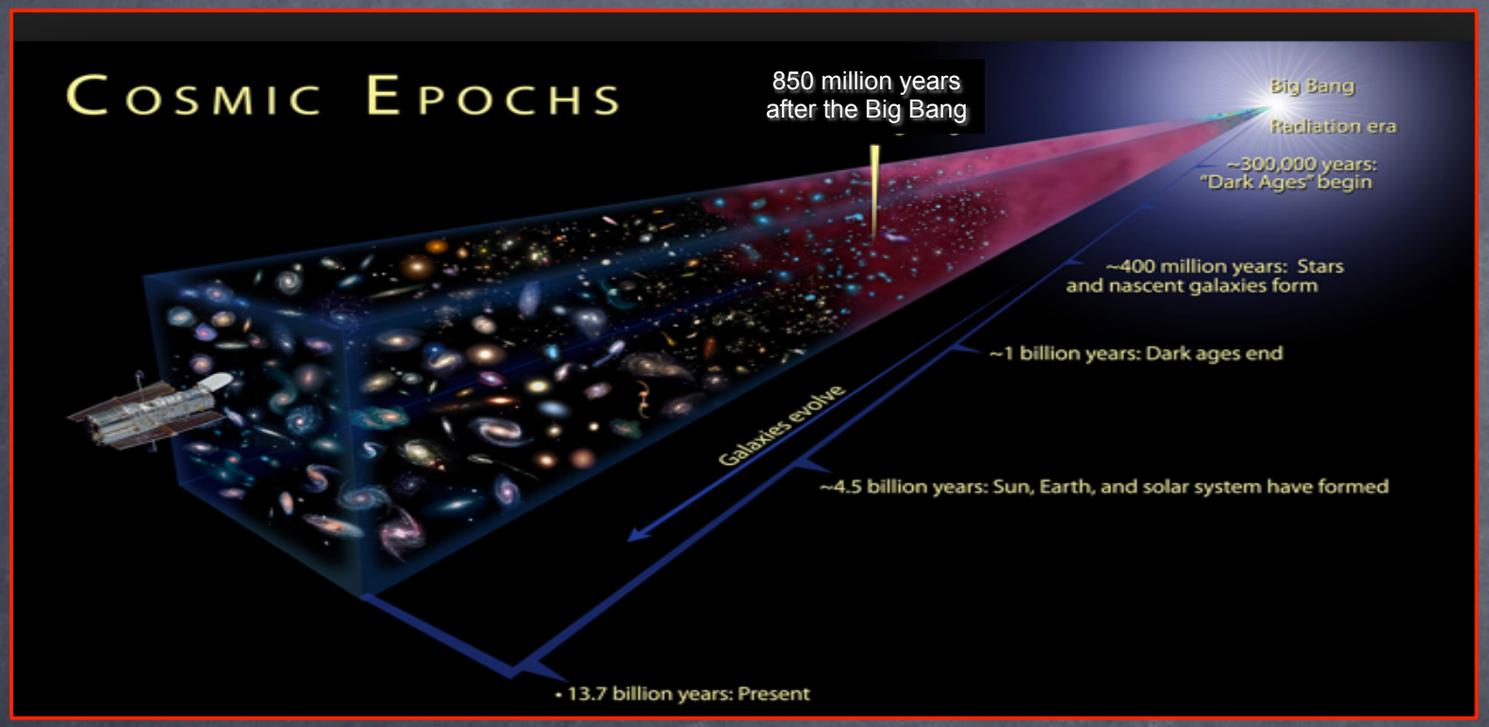

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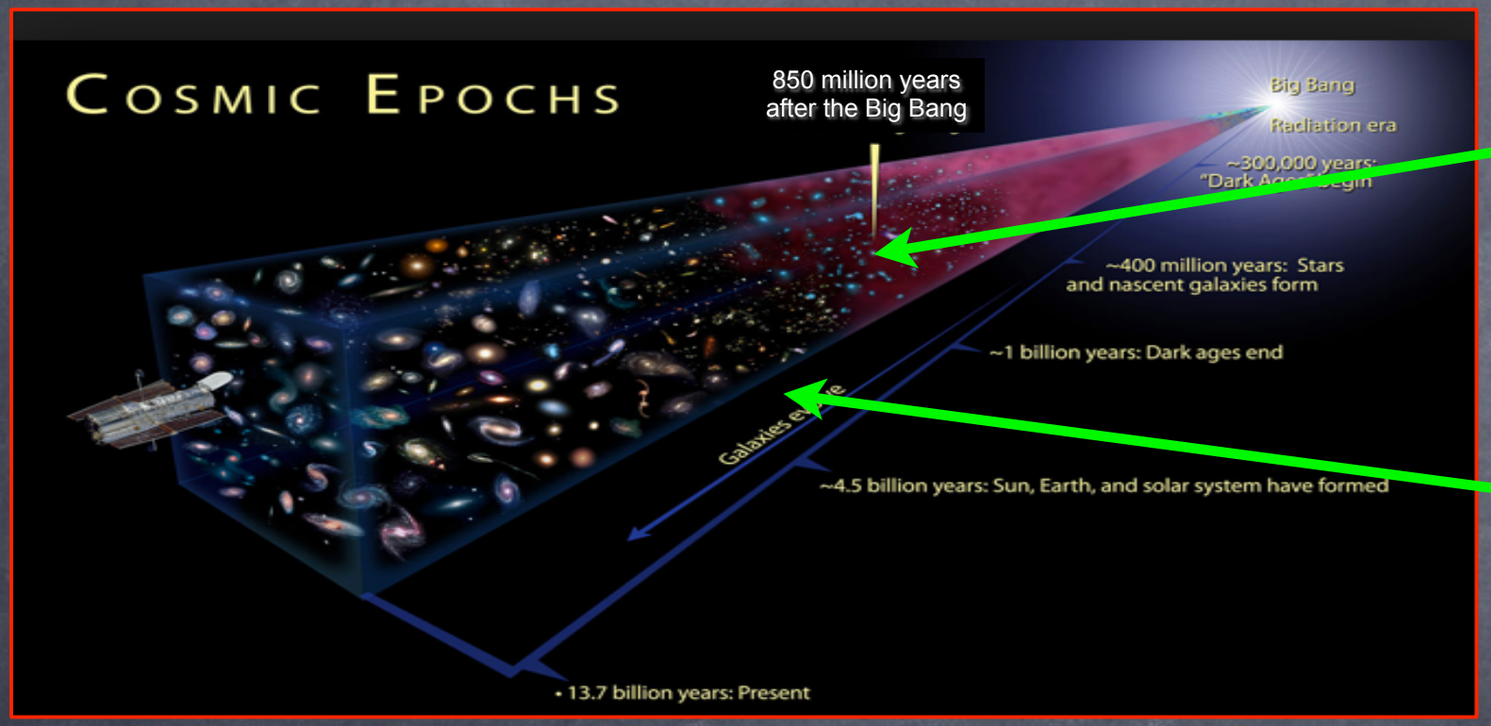

1) The search of z 6-7 galaxies

2) Looking at ionizing leakage at z≈3-4

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Deep spectroscopic search of z≃6 and 7 galaxies

VLT/FORS2 Large programme (ongoing)
(PI Pentericci - see NEXT TALK)

Run	Field	Total (hr)
190.A-0685(A)	UDS	15.0
190.A-0685(B)	GOODS	25.0
190.A-0685(C)	COSMOS	15.0
190.A-0685(D)	UDS	15.0
190.A-0685(E)	UDS	15.0
190.A-0685(F)	GOODS	25.0
190.A-0685(G)	COSMOS	30.0 (2x15)
		140hr

VLT/FORS2 Programme (PI Fontana)

Run	Field	Total (hr)
085.A-0844(A)	NTT	15.0 h
084.A-0951(A)	GOODS	18.0 h
085.A-0844(C)	BDF	15.0 h
088.A-0192(D)	UDS	15.0 h
		63hr

VLT/FORS2 Programme (PI Bunker) (Archive)

Run	Field	Total (hr)
088.A-0968(A)+ 088.A-1013(A)	HUDF	27.0
		27hr

We expect to obtain (including Vanz+09 + archive):

a) ≳ 200 spectra of z≃6 galaxies

b) ∿ 100 spectra of z≃7 galaxies

12-30hr integration time each (up to 50hr, e.g., V14b)

z=6 selection:

Homogeneously selected, **H-band based** (H < 27.5)
[i-z > 1.0 & J-H < 0.5] + non-detection optical
(e.g., Bouwens et al. 2014)

Current **z=6 sample: 150 deep spectra!**

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		140hr

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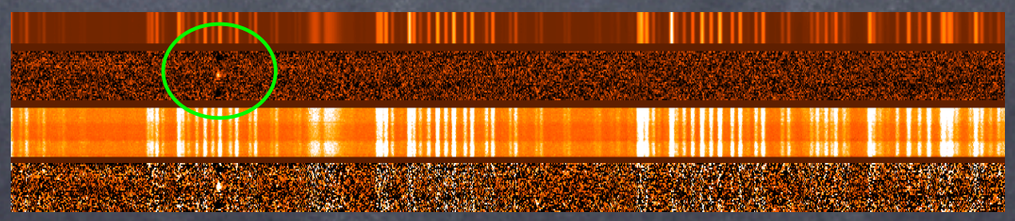
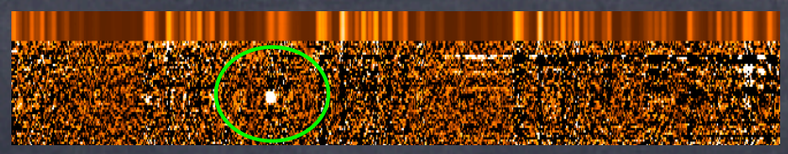
Current **z=6 sample: 150 deep spectra!**

"old" z_{850}-band selection favor faint LAEs:



z=5.92 - EW(Lya)=101A
z_{850}(obs)=27.50 & No H160
w/o Lya, z_{850} > 28.28



z=6.095 - EW(Lya)=330A
z_{850}(obs)=26.30 & No H160
w/o Lya z_{850} > 27.40

Deep (15-30hr) VLT/FORS2 spectroscopy at 5.7<z<7.11

z=5.783

z=6.337

z=6.635

z=6.665

z=6.740

GOODS-S
HUDF
30 hr

Sky

S/N

RMS

Reduced

z=7.008

z = 7.040

z = 7.109

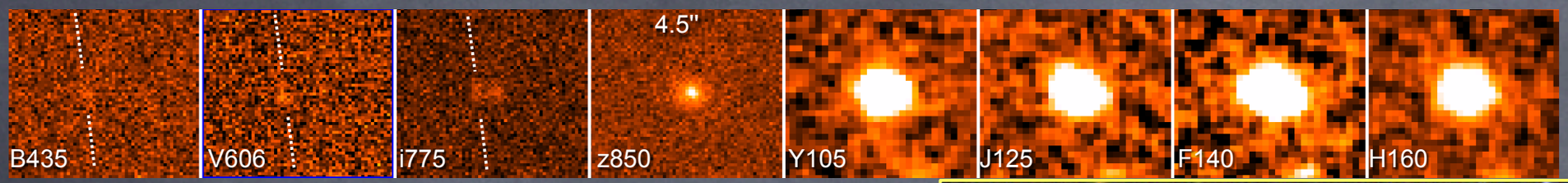
S/N(LyA)

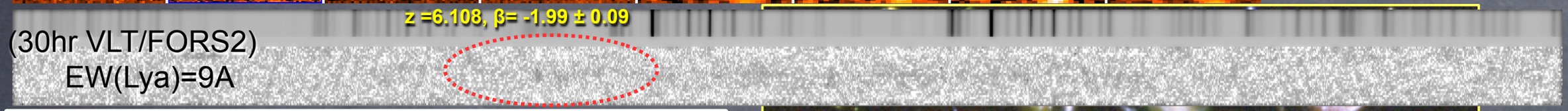
z=5.7

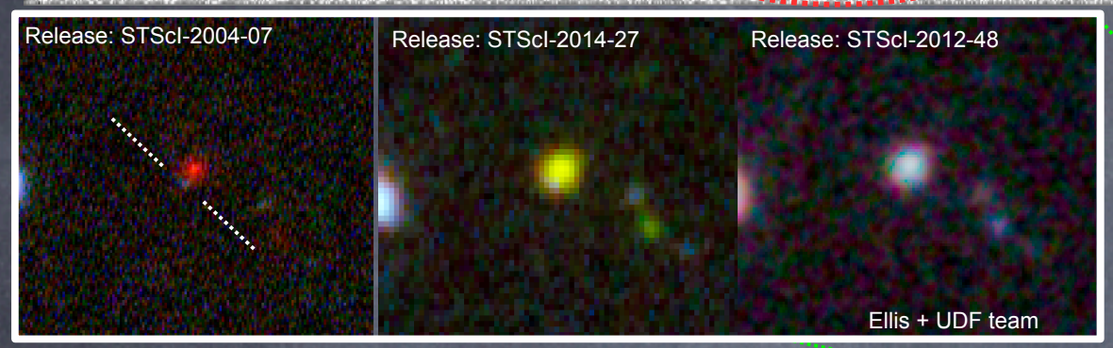
z=7.3

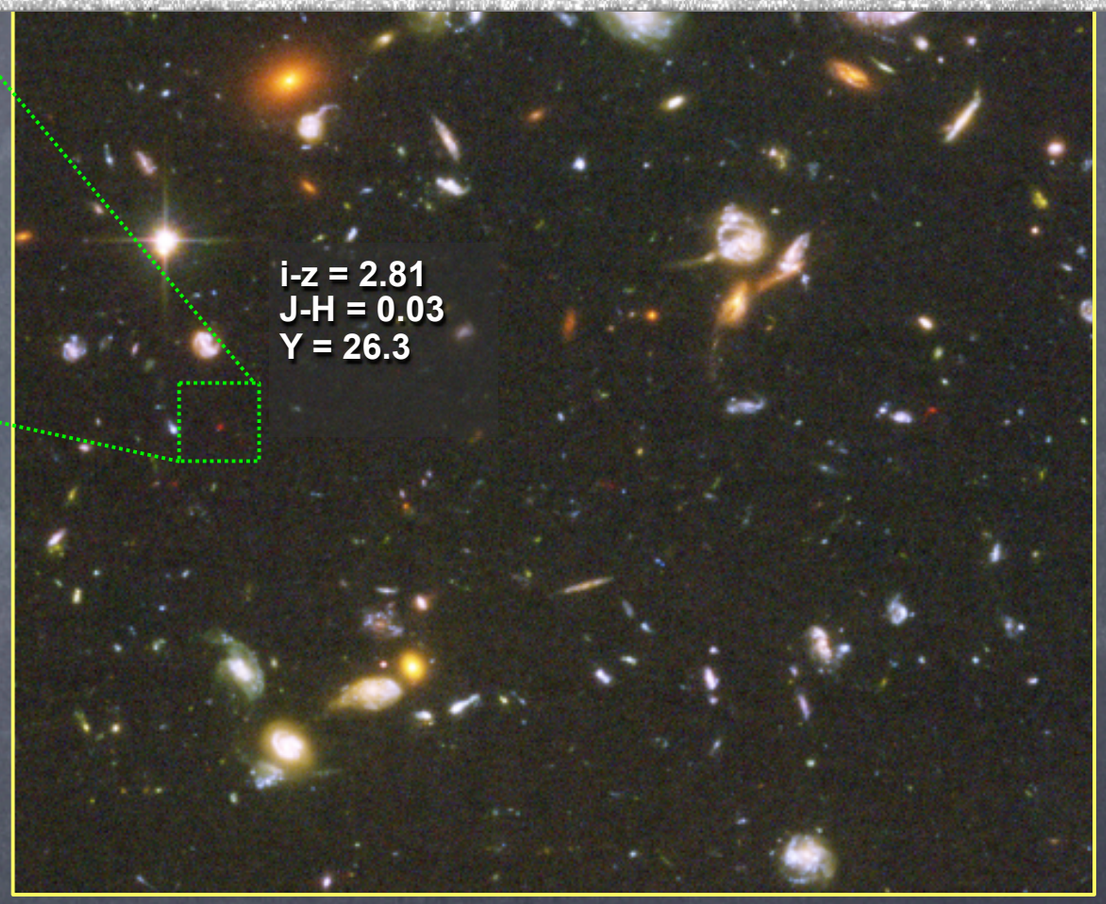
V14b

Deep spectroscopy reveals weak Lya+continuum at z≃6 (m1500≃26)









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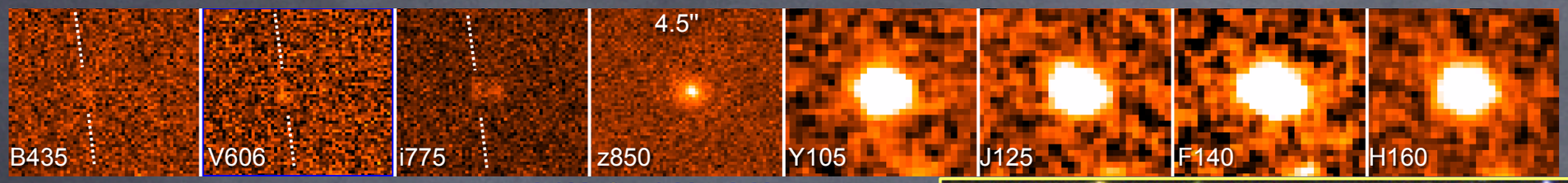
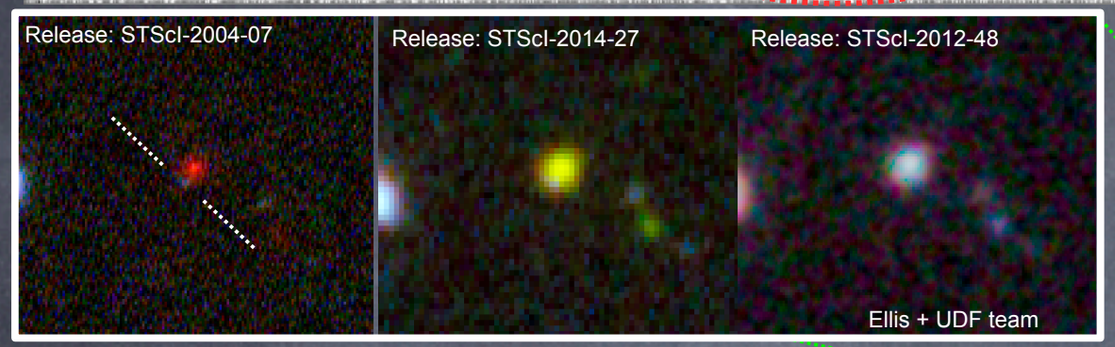
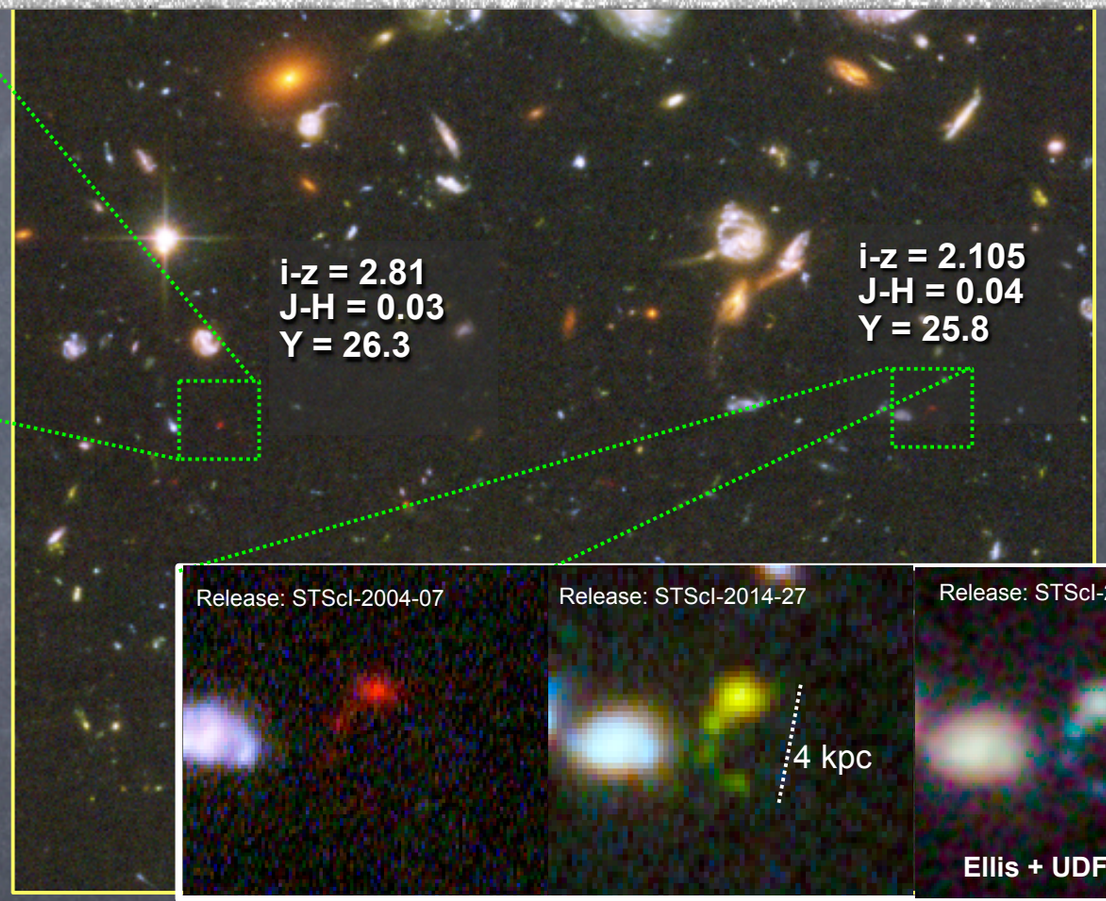
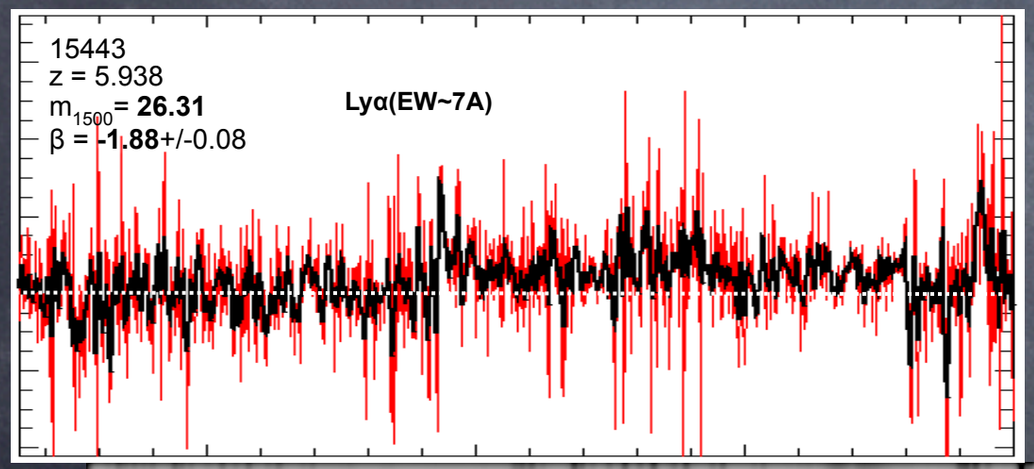
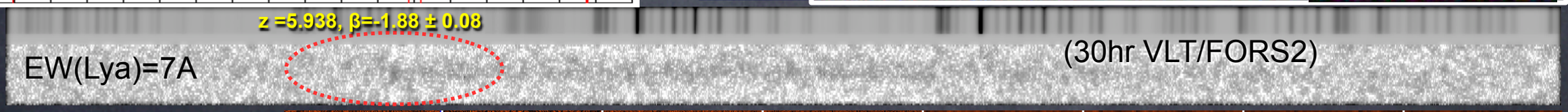
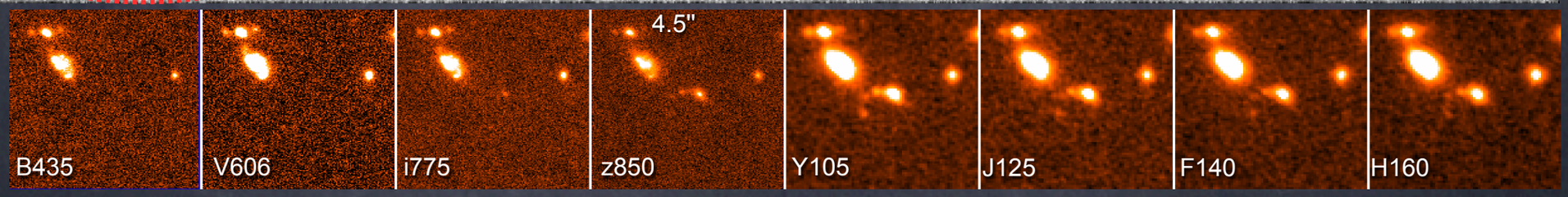






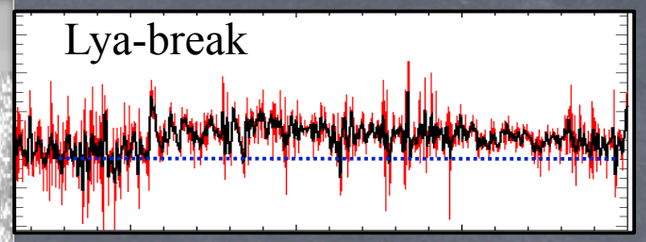




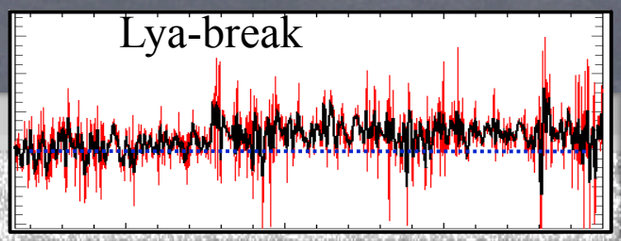


Deep spectroscopy reveals faint z≃6 non-Lya emitters

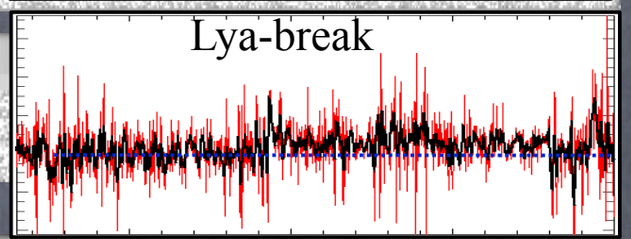
BDF5870,
z=5.632,
β= -1.38 ± 0.14
m_{1500}=24.88



26560,
z=5.805,
β= -1.28 ± 0.24
m_{1500}=24.92



15443,
z=5.938,
β= -1.88 ± 0.08
M_{1500}=25.77



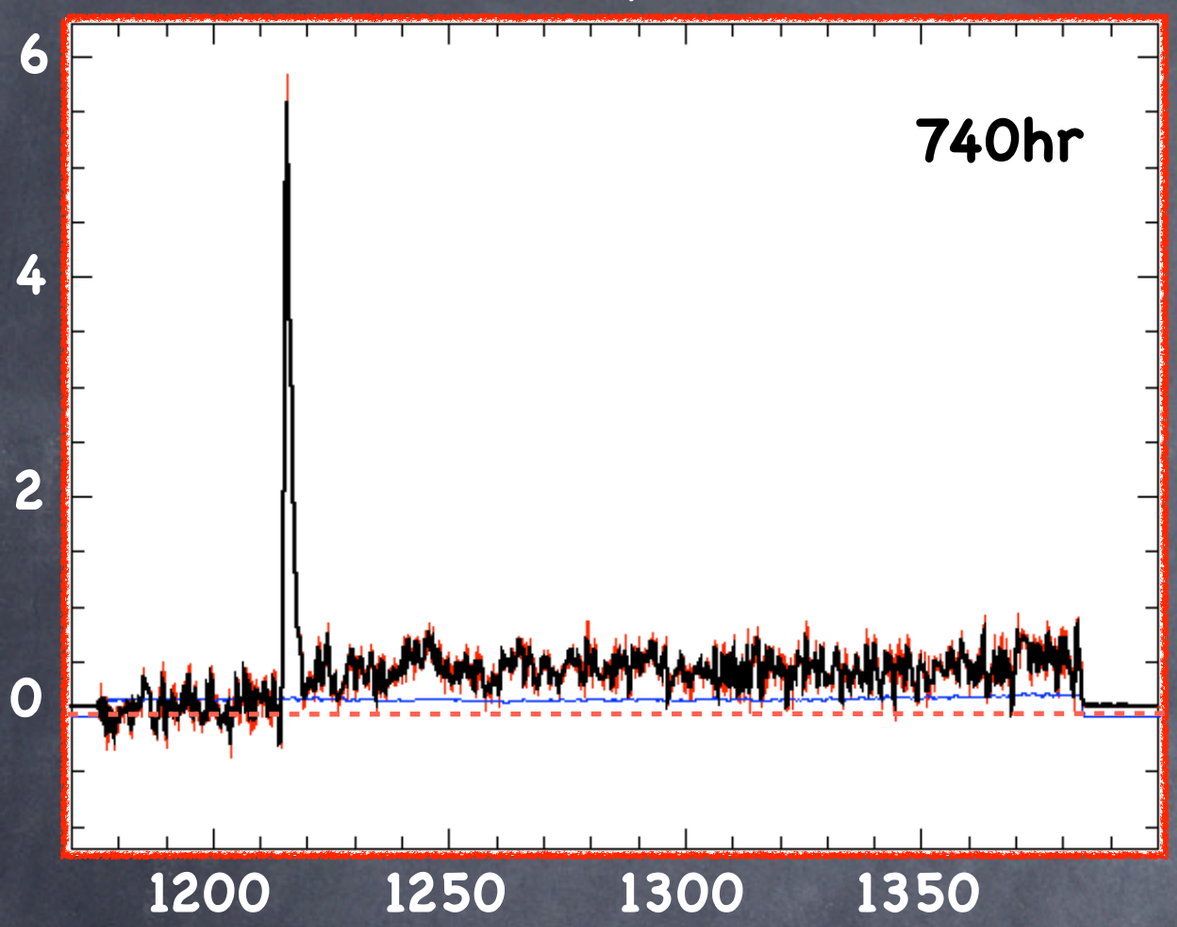
16371,
z=6.108,
β= -1.99 ± 0.09
m_{1500}=26.32

20776,
z~6.2,
β= -1.64 ± 0.18
m_{1500}=25.63

UDS , 29249
z~6.3,
m_{1500}=25.8

Deep Stacking at z=6

VLT/FORS full sample



Deep Stacking at z=6

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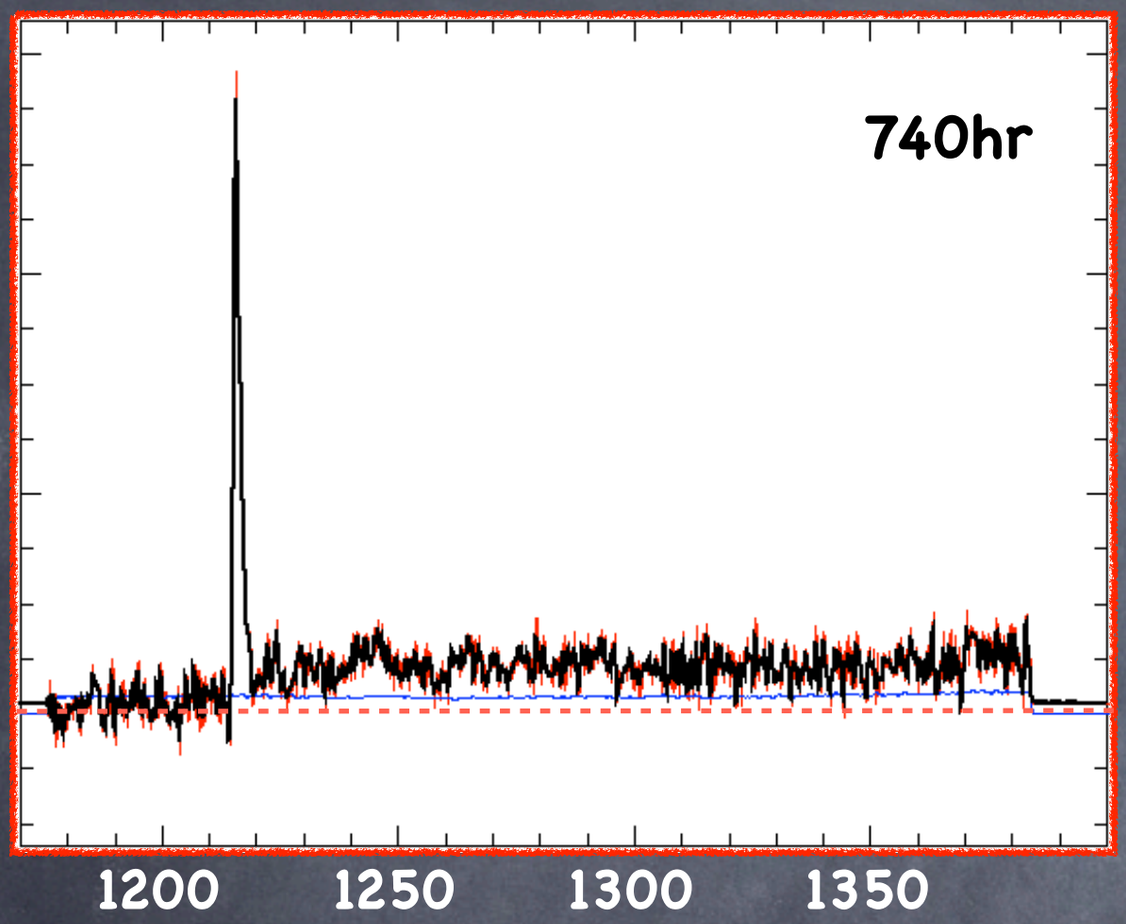
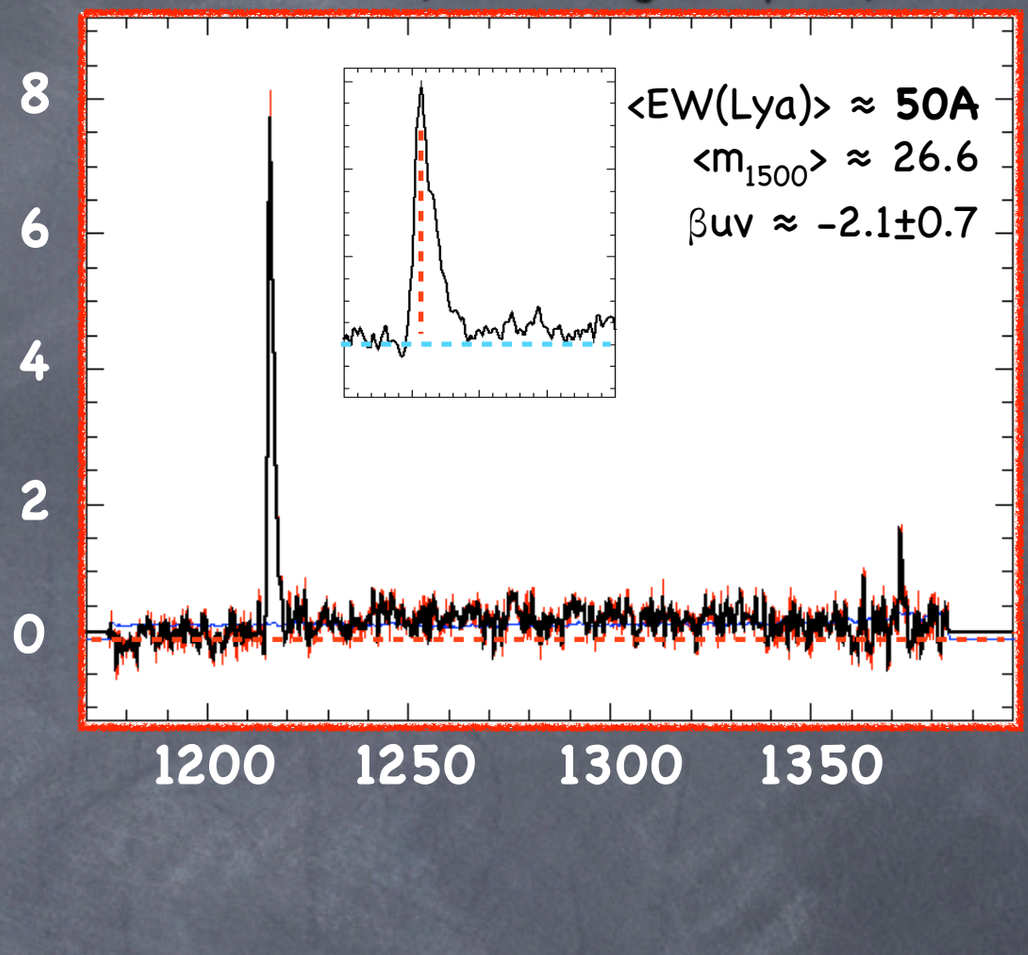


EW(Lya)>20A

(400 hr) EW(Lya)>20A good-quality



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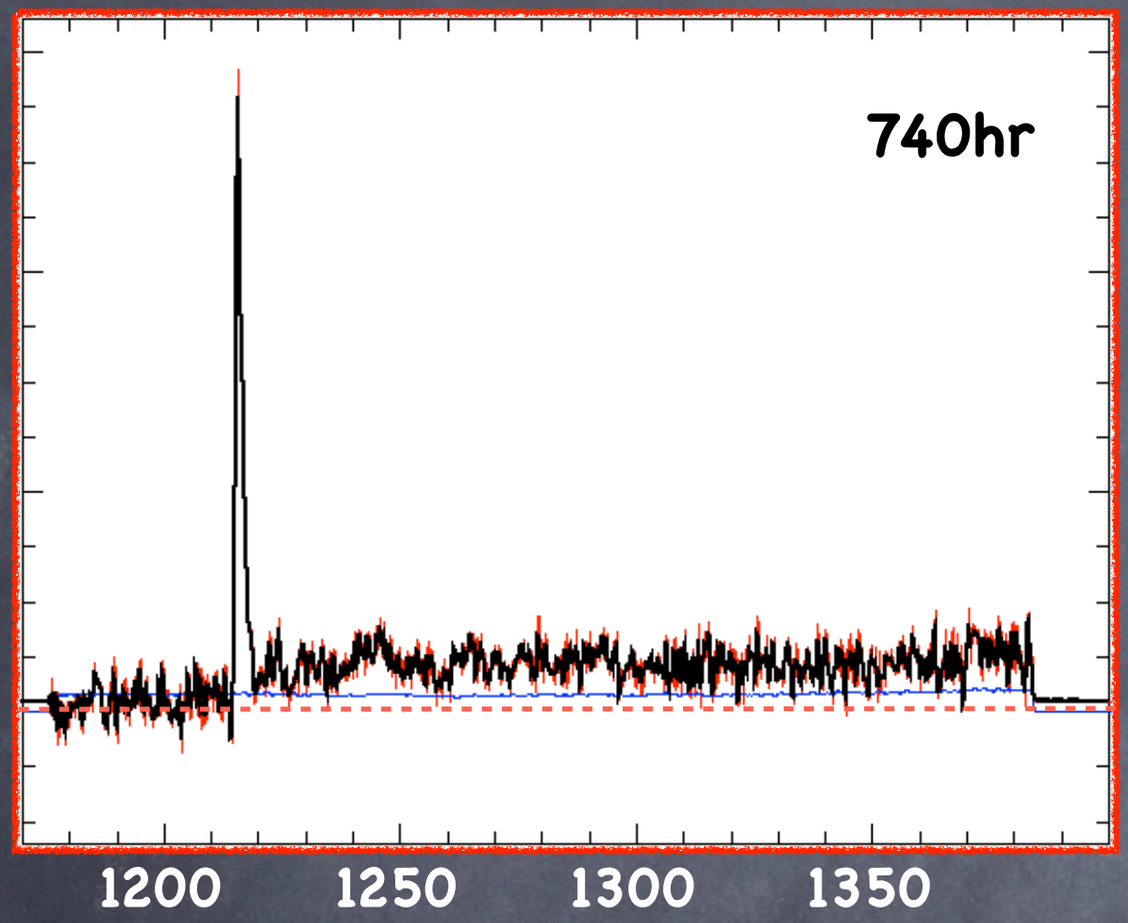
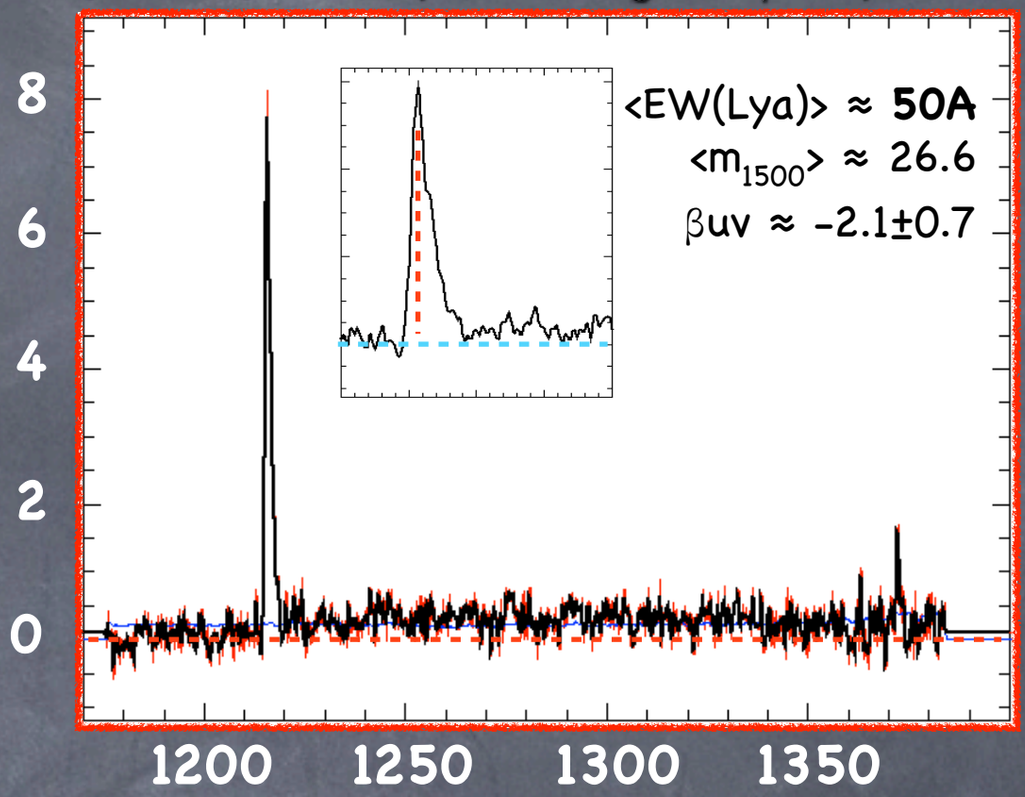


EW(Lya)>20A

EW(Lya)<20A

(400 hr) EW(Lya)>20A good-quality



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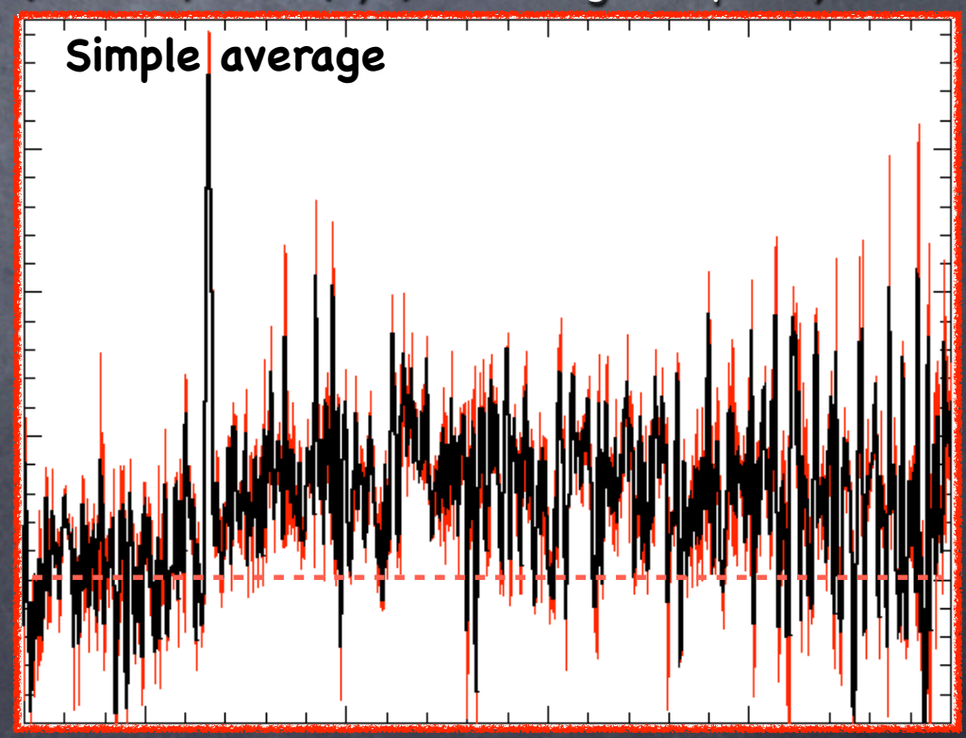

Deep Stacking at z=6

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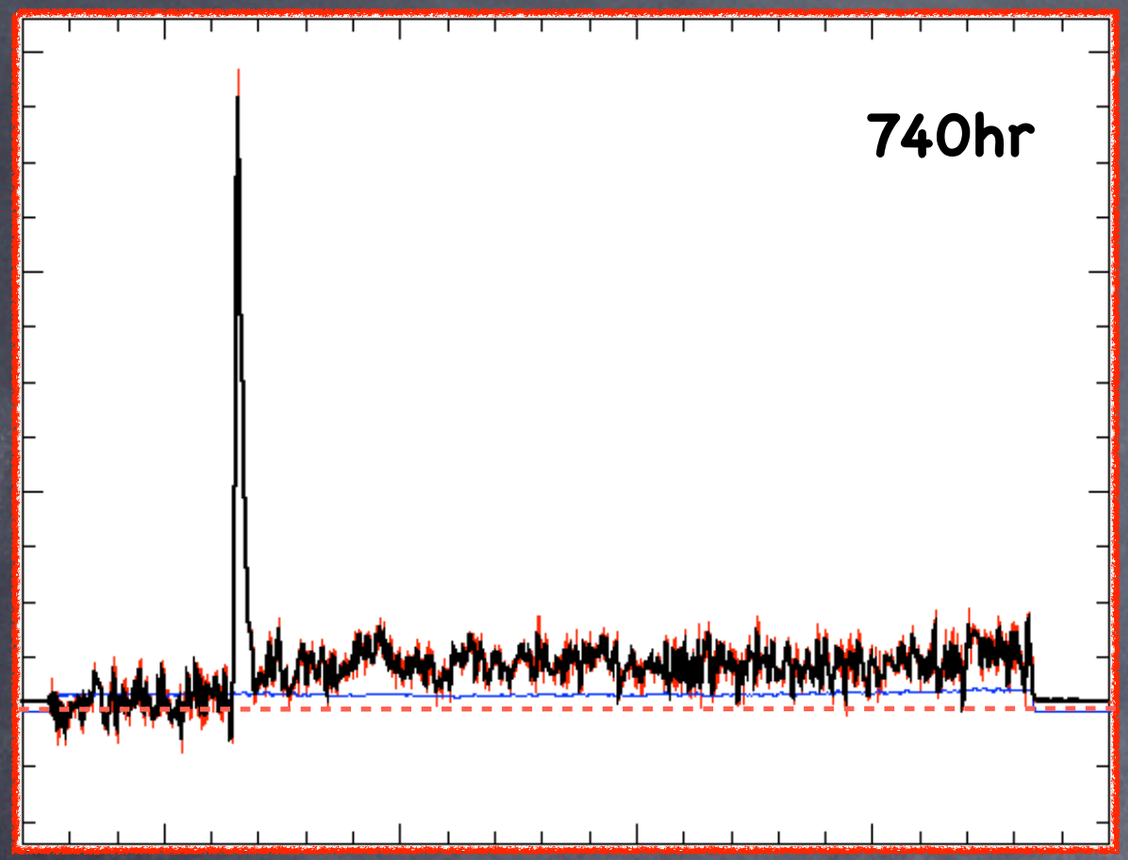

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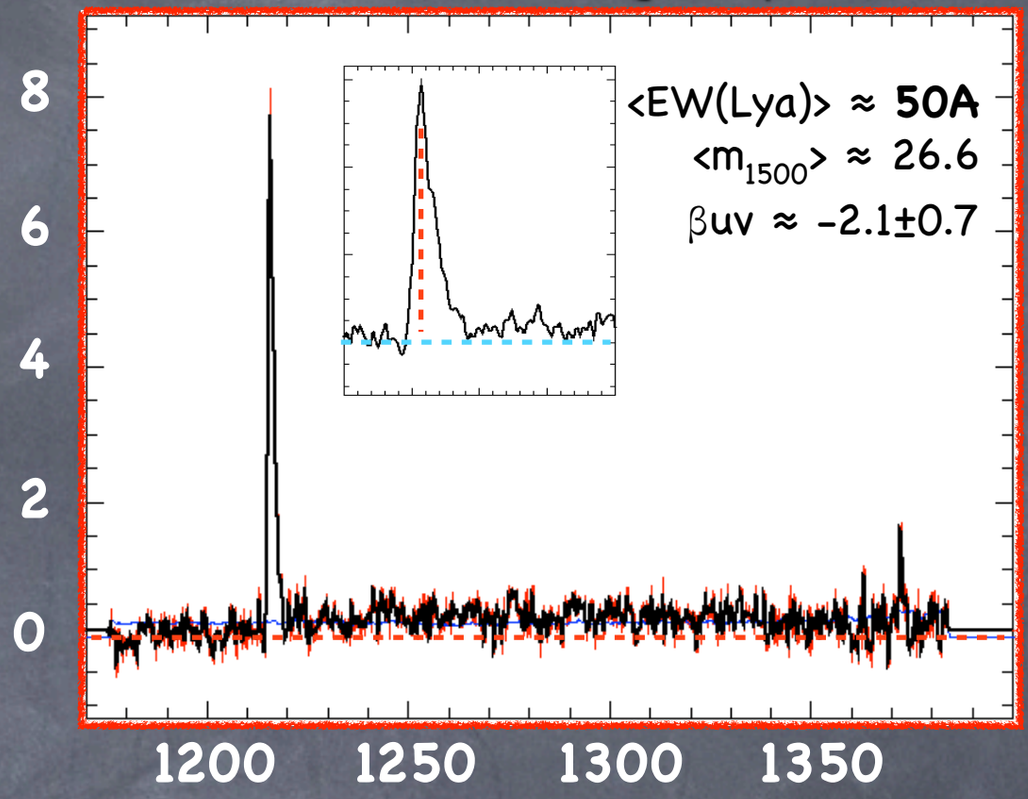

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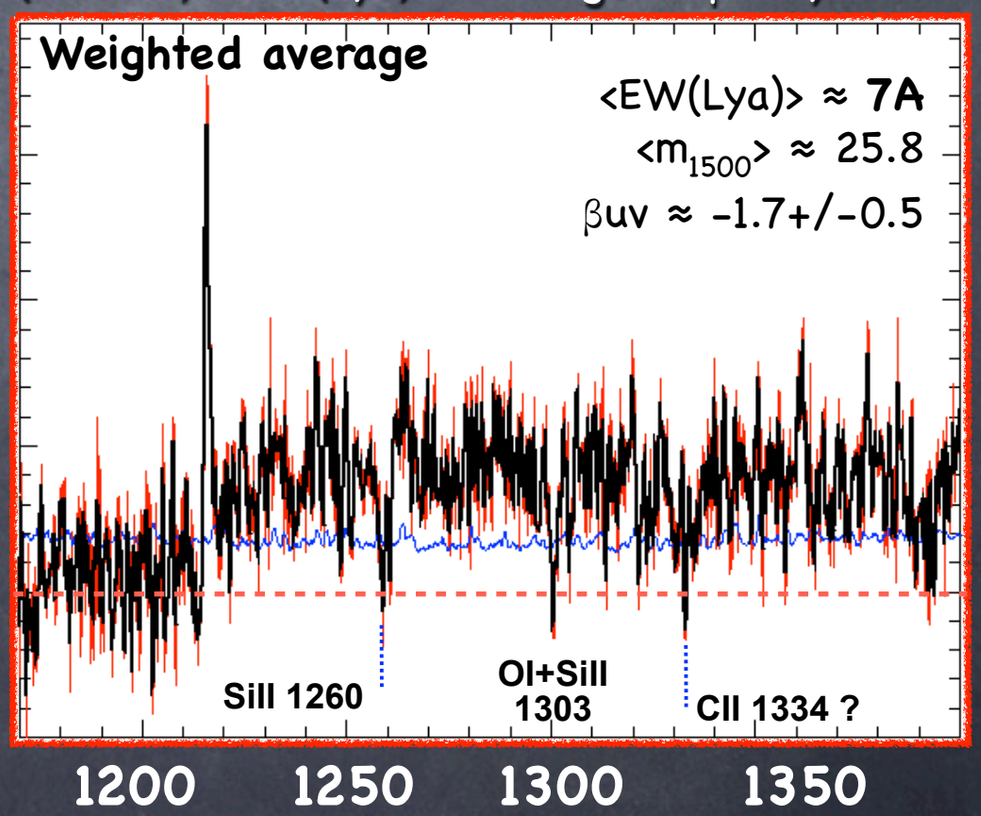

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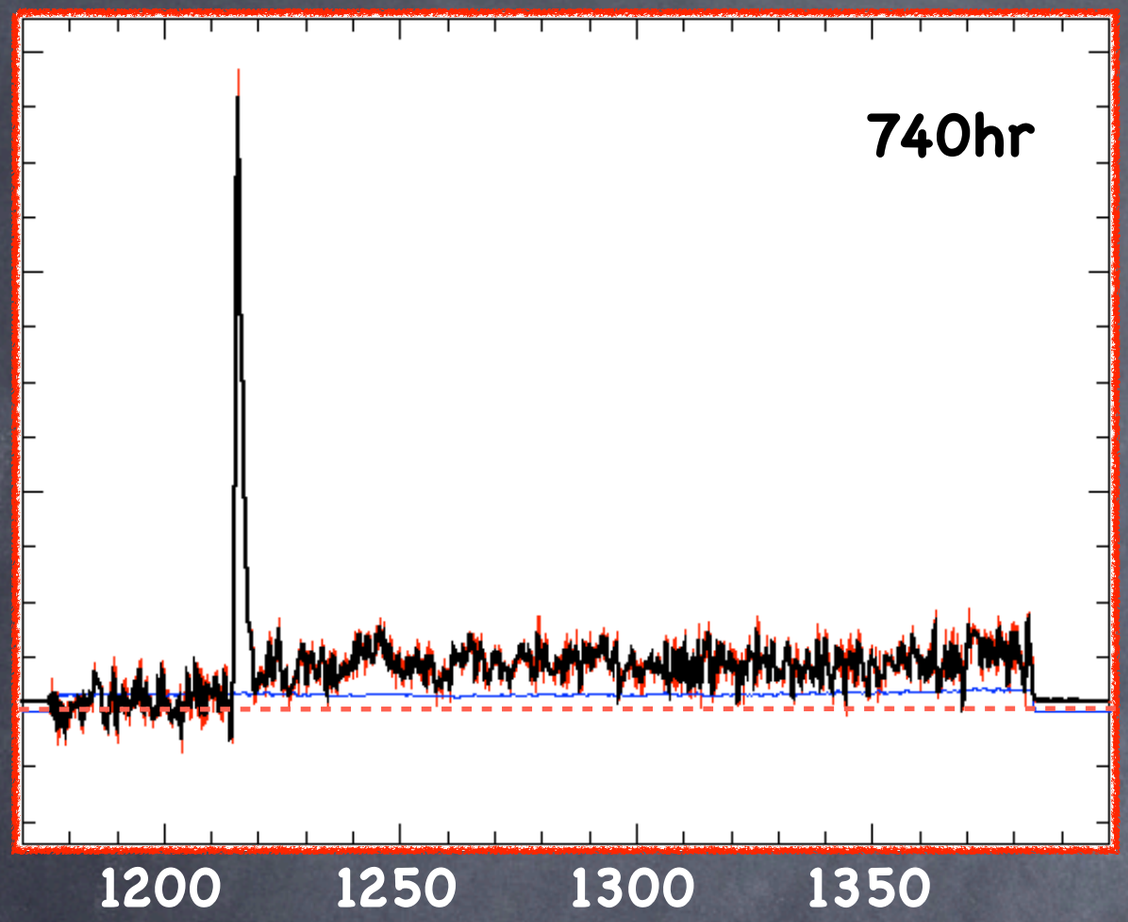

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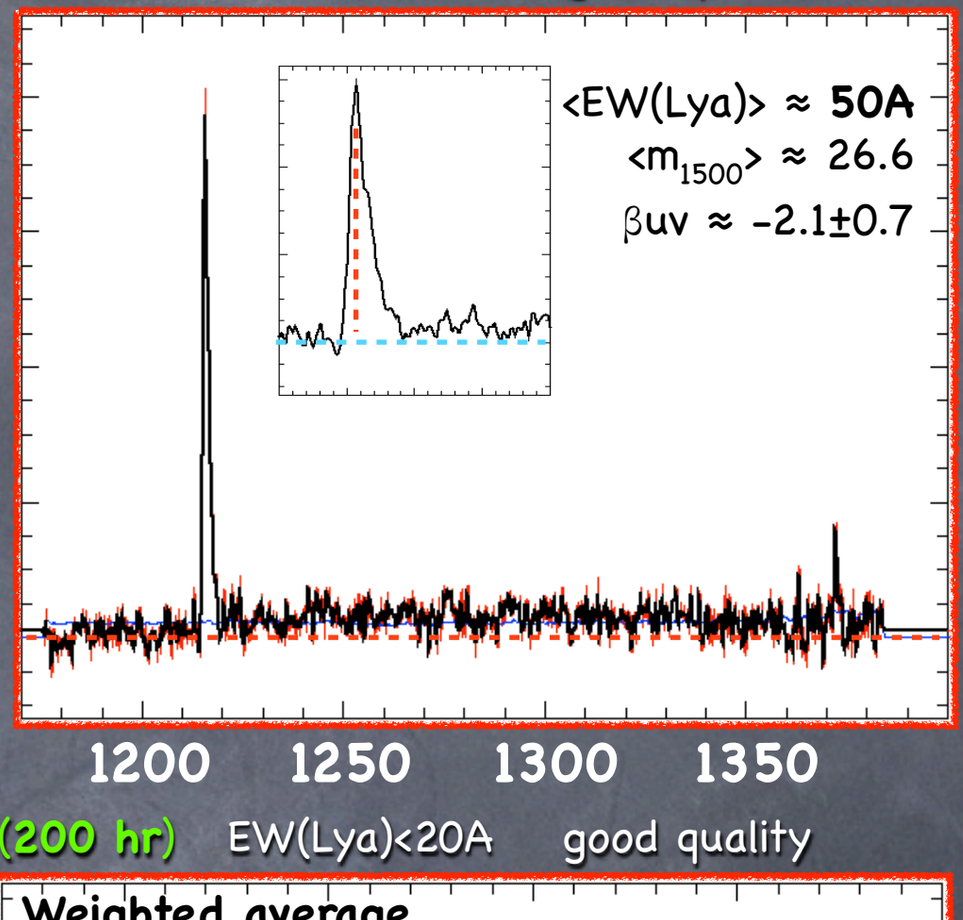

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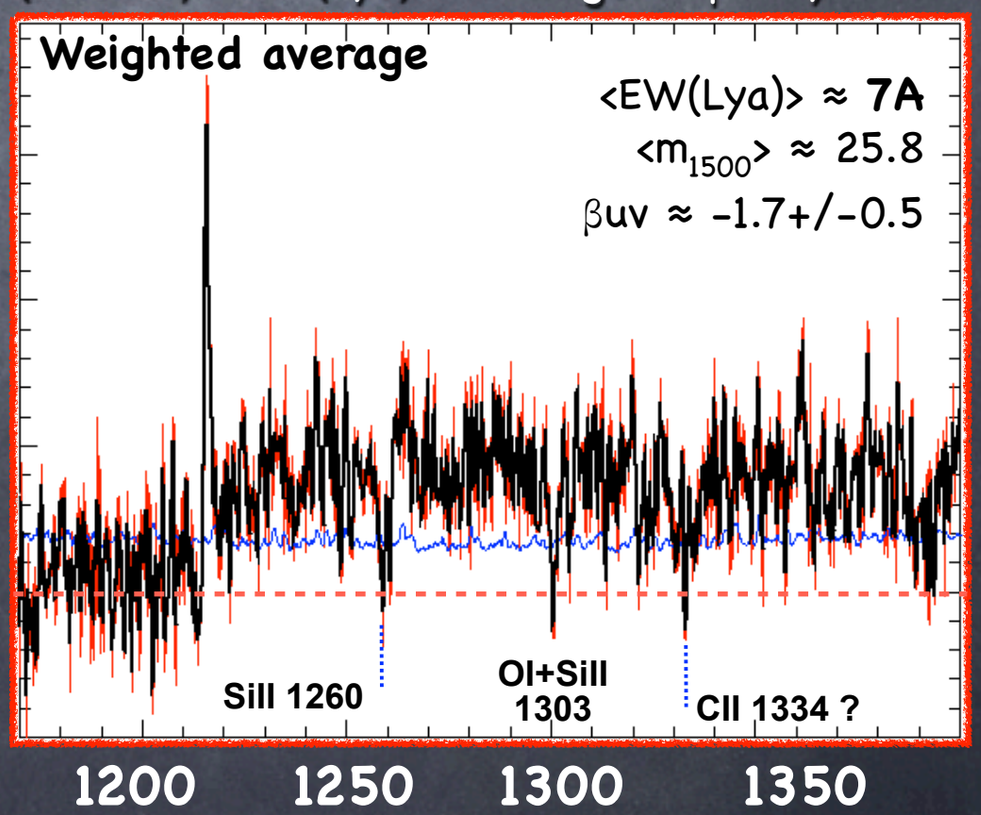
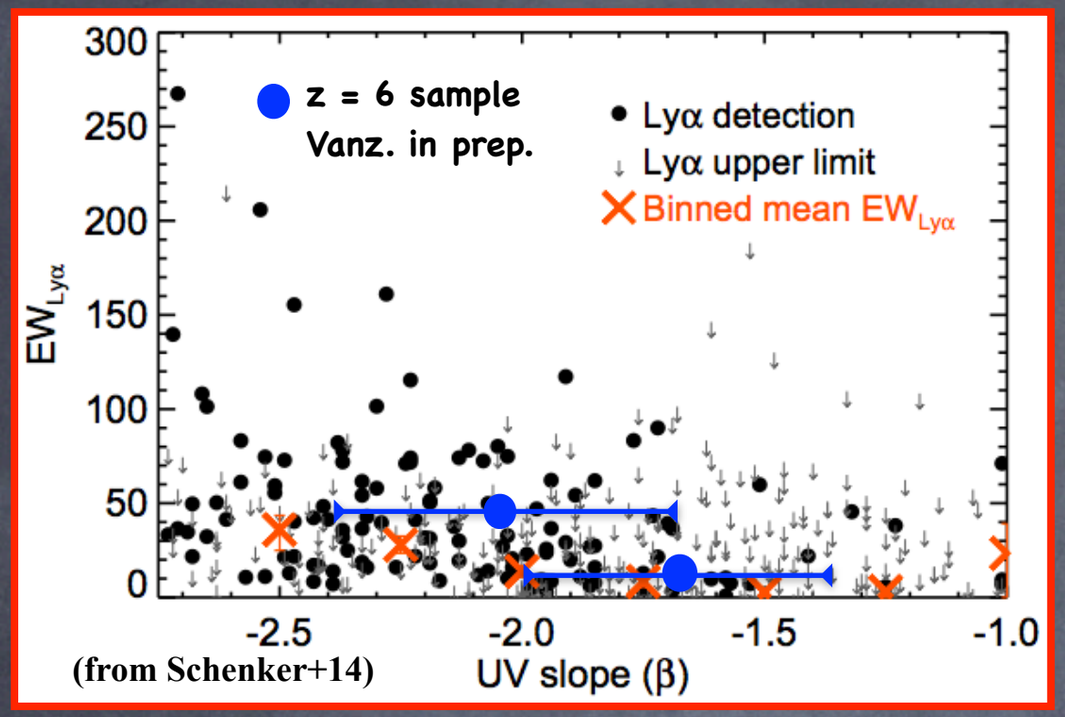


Measure redshift for faint (mag≈26) z≈6 non-LAEs:

1) first time, not trivial,
   ~ half of the LBG population
2) perform stacking, study properties:
   → UV slope, ISM lines, size ...
   similar to lower-z (Shapley+03; Vanzella+09)
3) better characterization of the Lya demography,
   comparison with the occurrence at z>6.5 → EoR

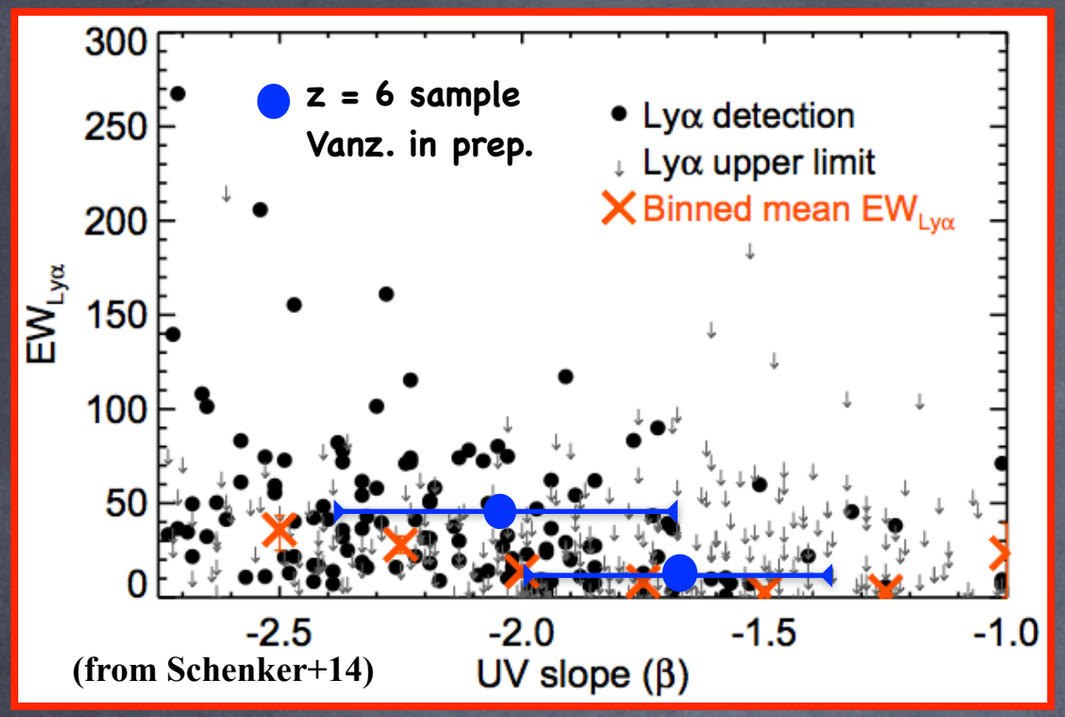
Fraction of Lya lines at z≃6 and UV slope dependency



(from Schenker+14)

UV slope derived from multi-band fitting,
best quality spec., not clear separation
between emitters and non-emitters

Fraction of Lya lines at z≃6 and UV slope dependency



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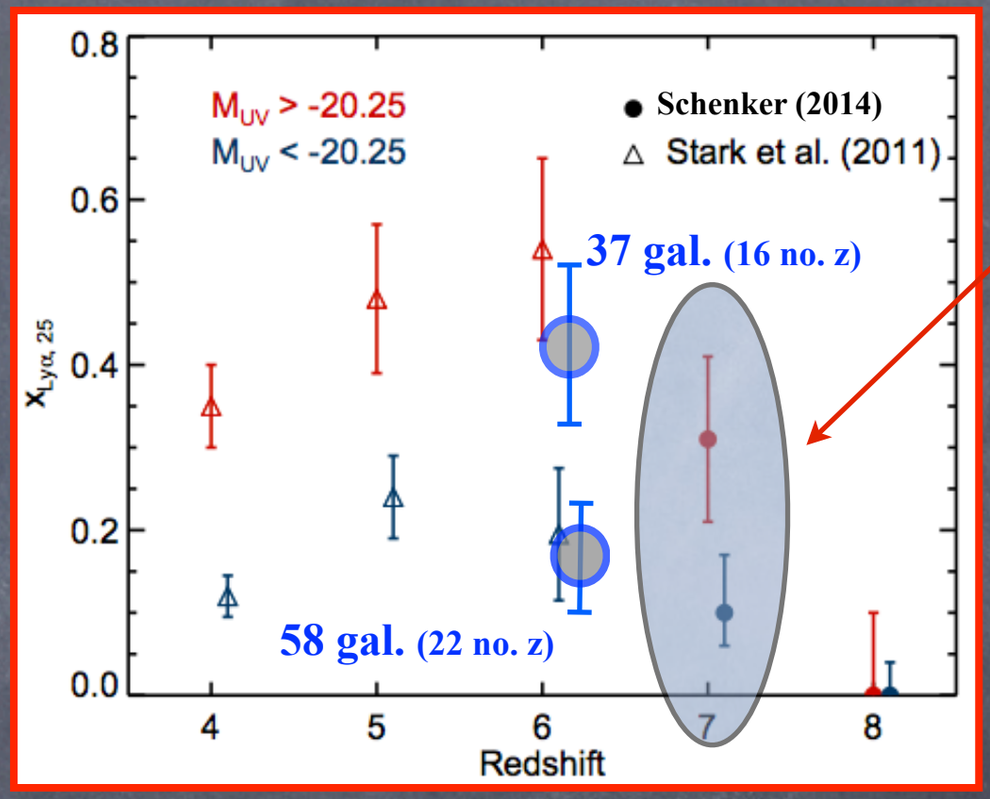
EW(Lya)>25A (EWlim<25A)



see next talk Pentericci

146 with spectrum: z>5.5 or no-z (current+previous surveys)
130 H-band detected, match color criterium (i-z>1 & J-H<0.5)
95 have observed EW limit <25A (3-sigma)
➜ 37 Muv>-20.25 43% with EW(Lya)>25A
➜ 58 Muv<-20.25 17% with EW(Lya)>25A

... faint z>6 galaxies spectroscopically confirmed ...

… faint z>6 galaxies spectroscopically confirmed …

Brute force:

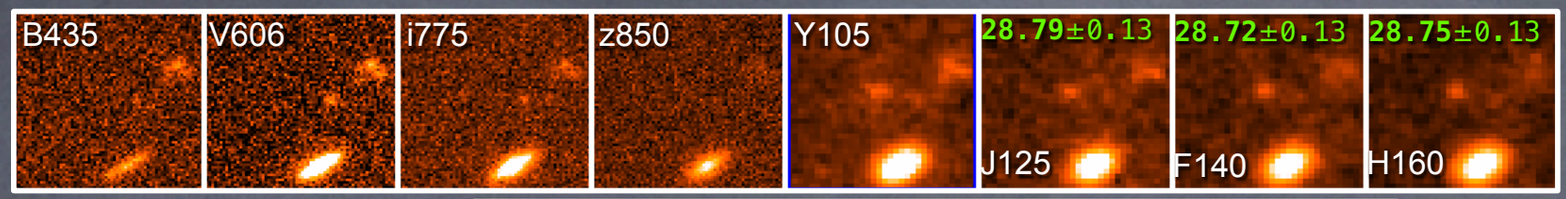
VLT/FORS 30hr

HUDF

z=6.635

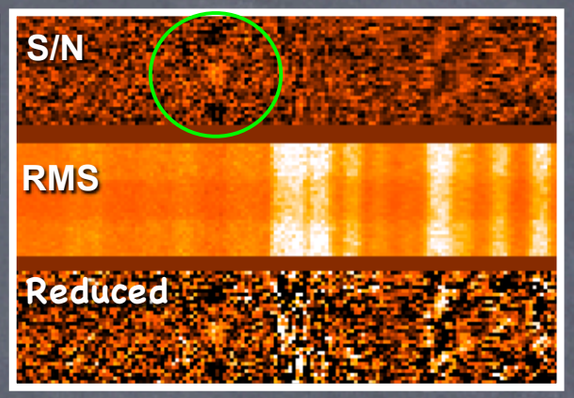
Mabs = -18

F160W=28.8



Wilkins/Bunker+11, McLure+11 (HUDF2701) zphot=**6.66** [6.35-6.91], β=-3.3+/-1.5 (McLure+)

f(Lya)=2x10^{-18}erg/s/cm2 (S/N=7), EW=65A



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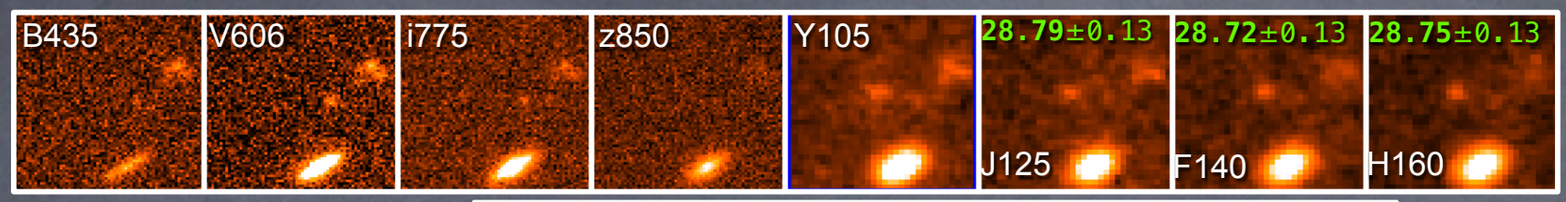

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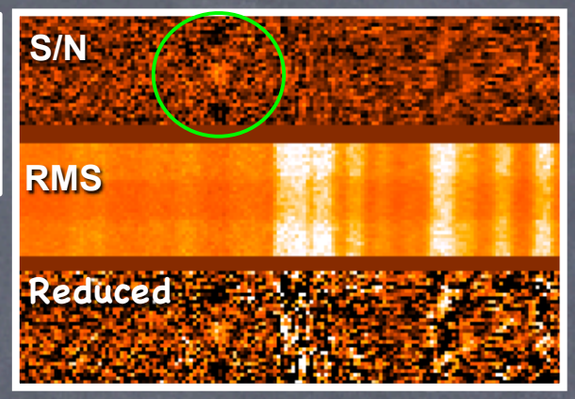


LBT/MODS 5hr

Newborn galaxy?

z=6.4

Vanz(2014a)

Mabs = -17

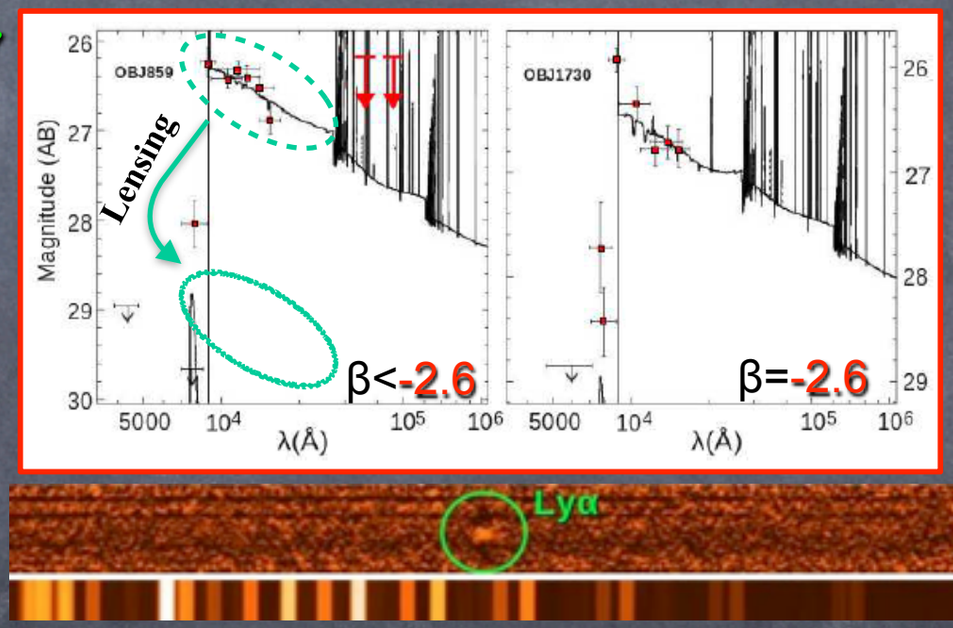
SFR<2 $M_\odot$/yr

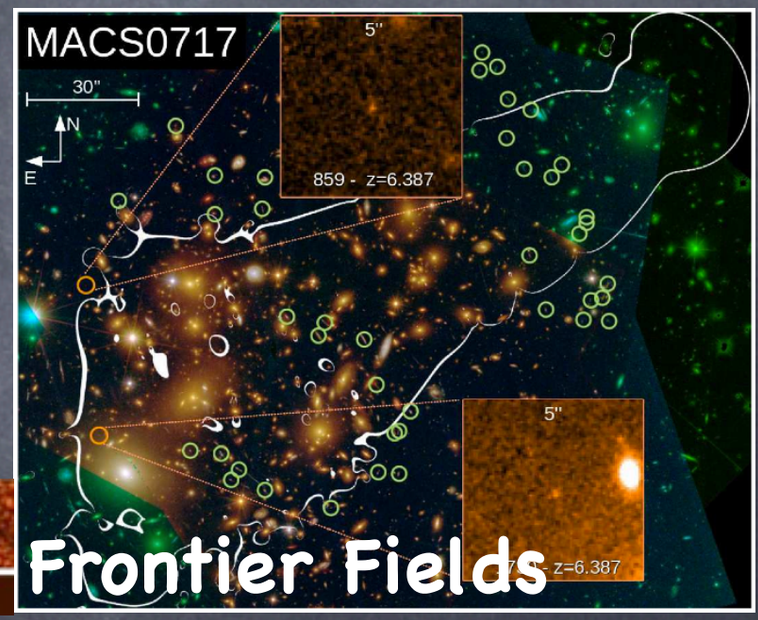
< 1sq.kpc,

$M^*<10^8 M_\odot$,

E(B-V)=0,

age~20Myr,





… how can we infer the escaping ionzing radiation from z>6 sources ? (LyC not visible directly at z>6)

(see also Castellano`s talk)

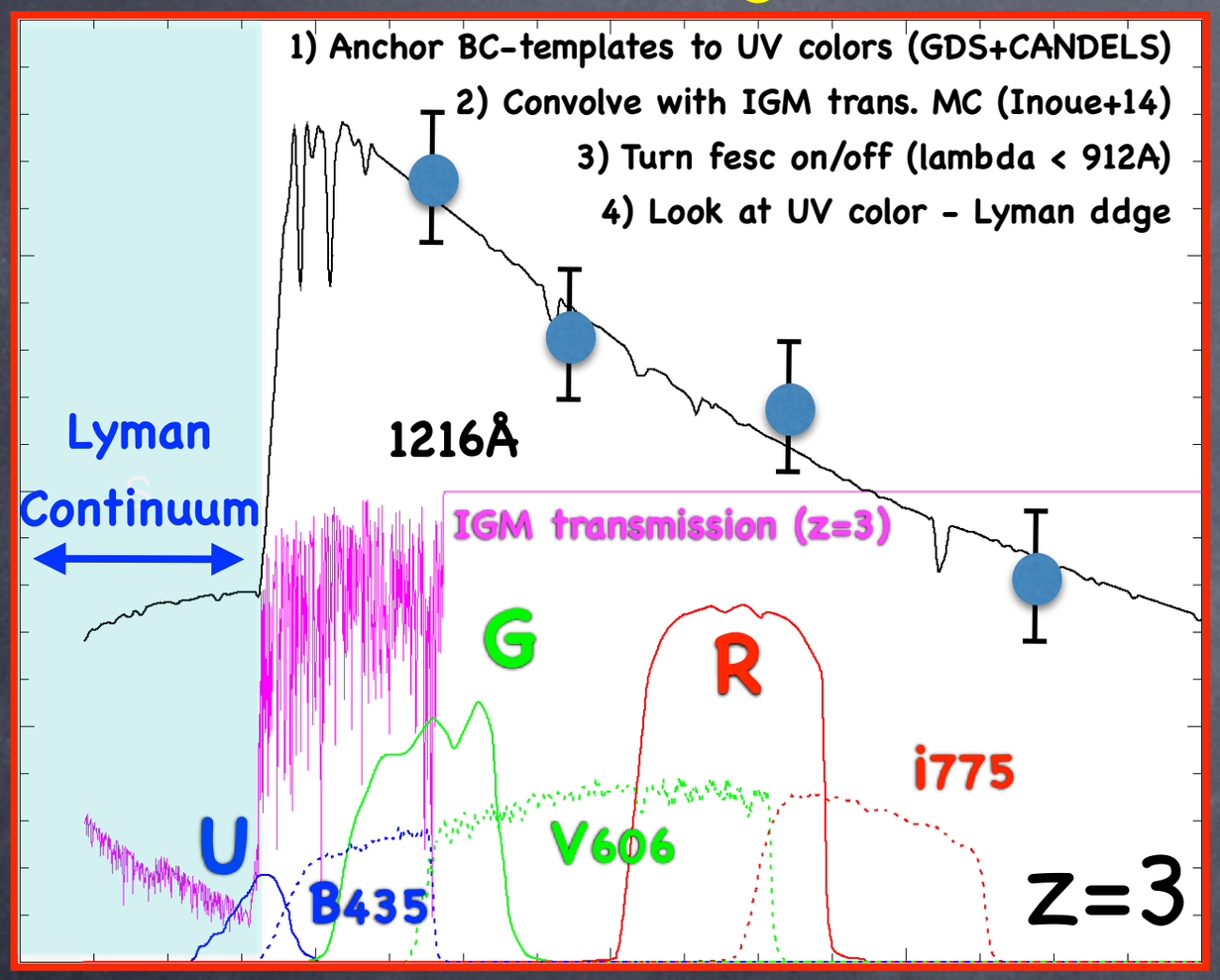
Investigating LyC sources at moderate redshift, z<4

Motivation: identify **non**-ionizing signatures of LyC leakage, learn and apply to z>>4 (JWST/ELT)

Very RARE at z<4 and L>0.1L* (see V10, V12, Siana+15, Grazian`s and Guaita`s talks),

However we can select candidate "ionizers" (V15)

Methodology



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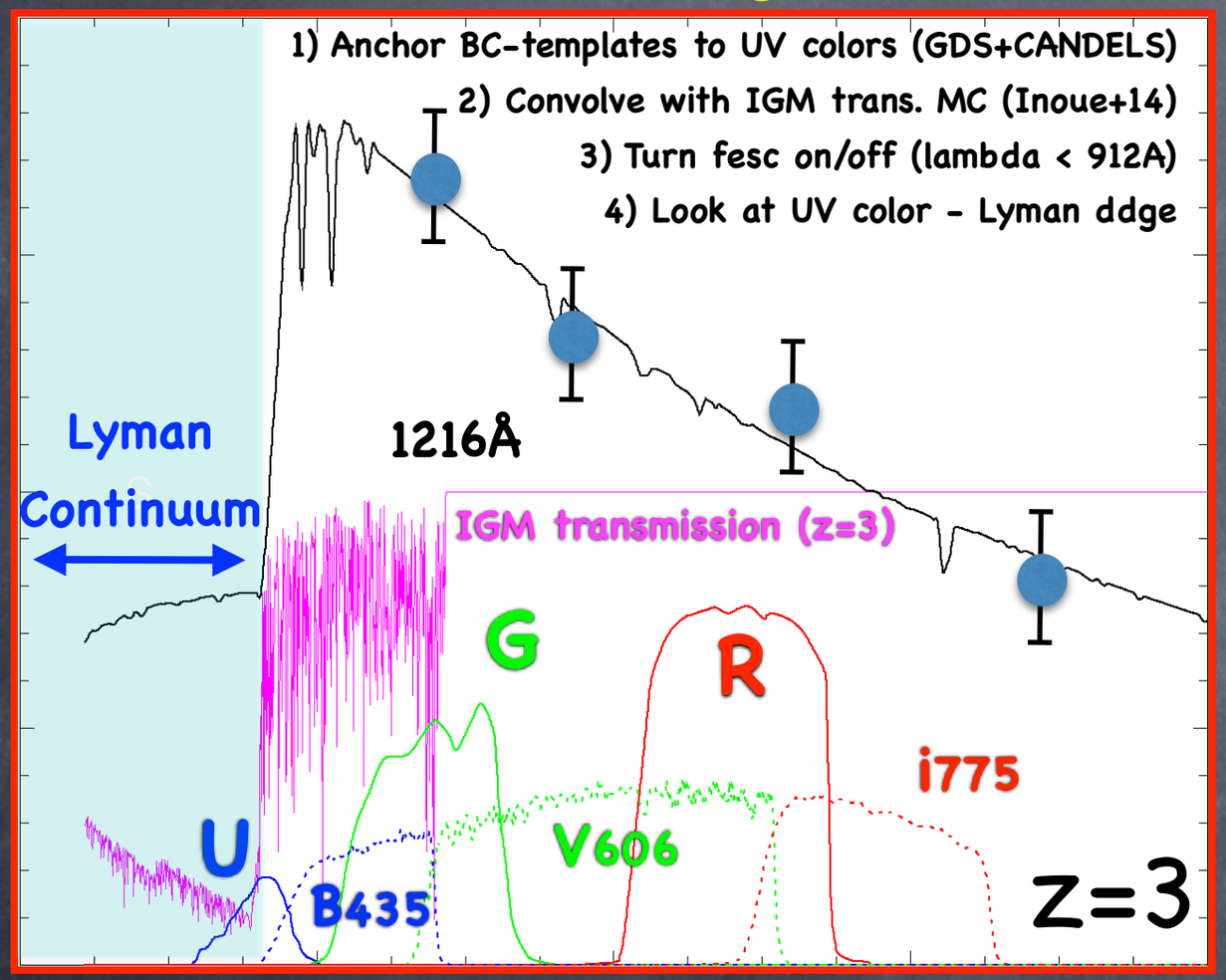
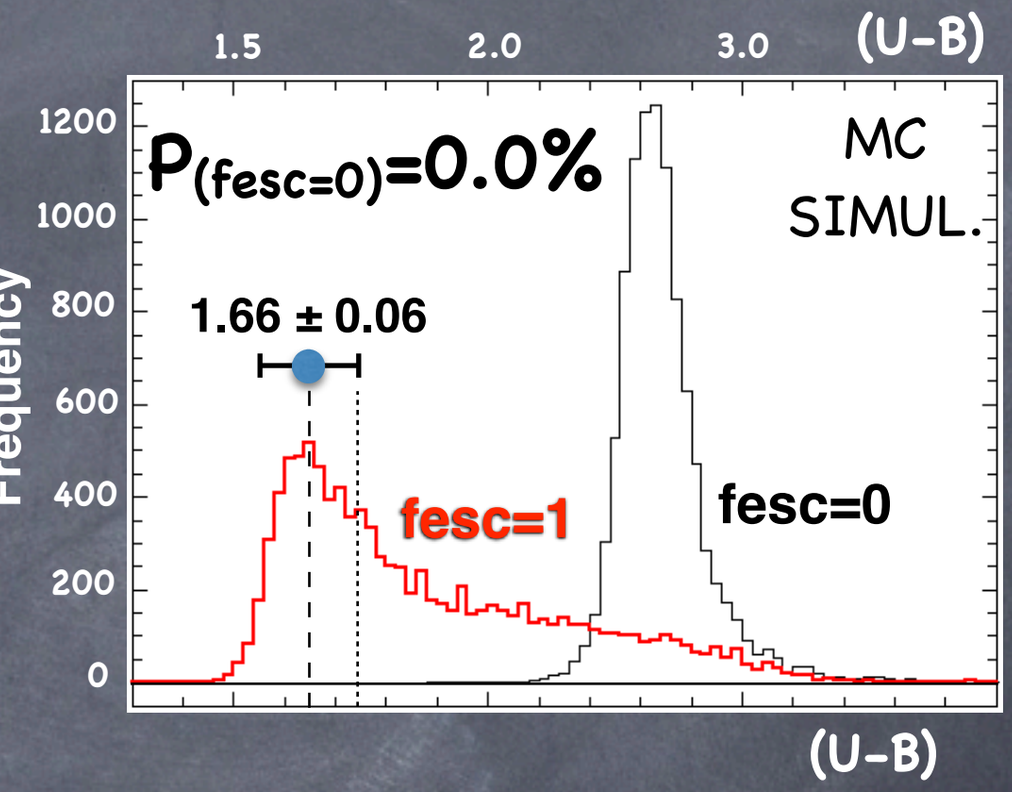
Very RARE at z<4 and L>0.1L* (see V10, V12, Siana+15, Grazian`s and Guaita`s talks),

However we can select candidate "ionizers" (V15)

Methodology





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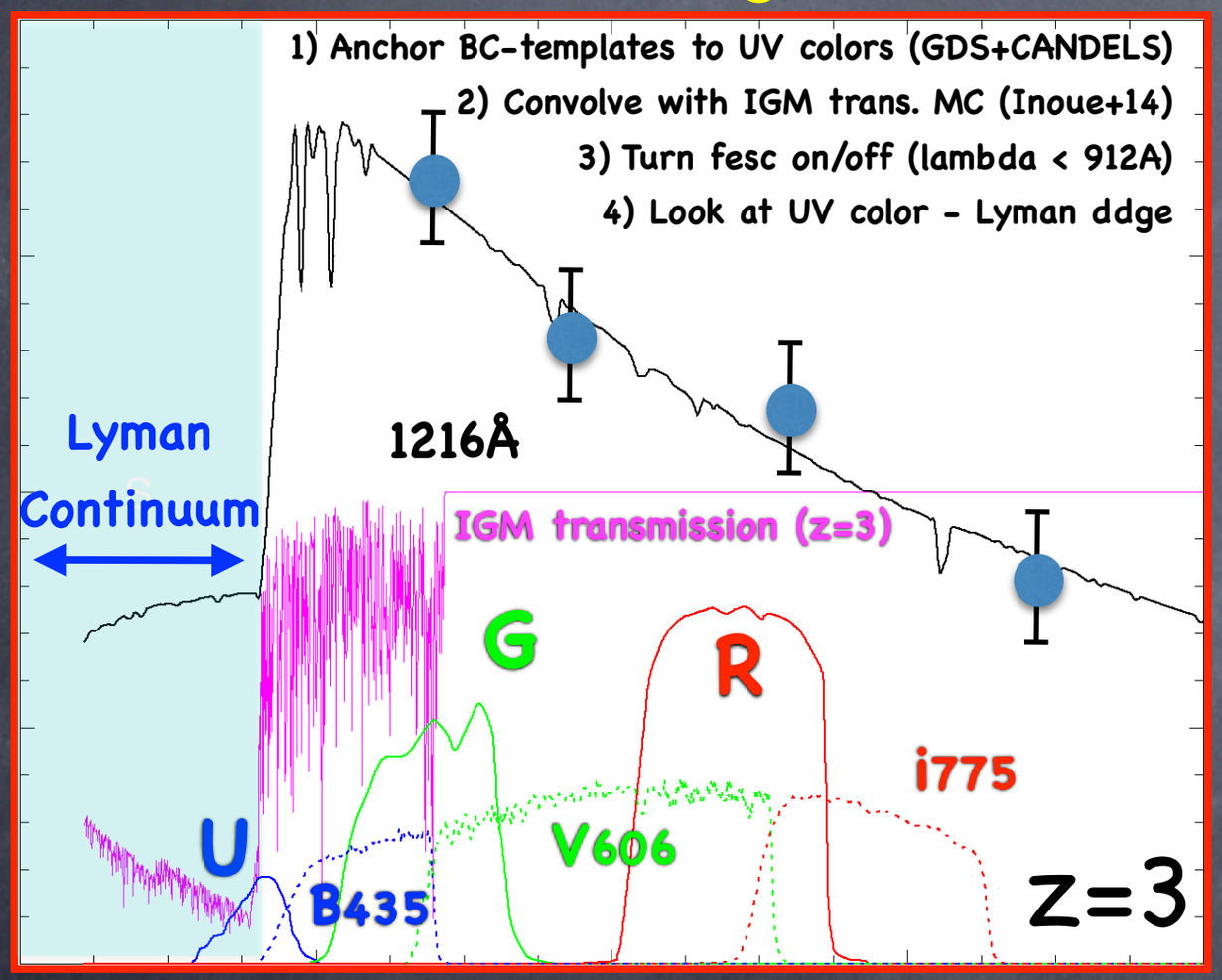

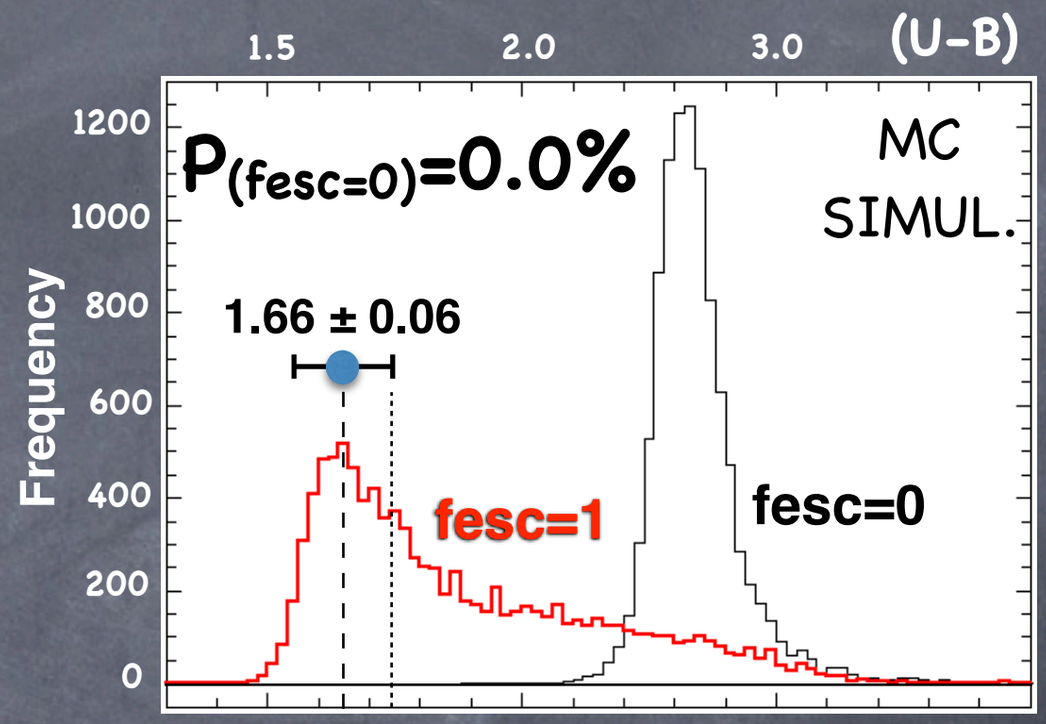

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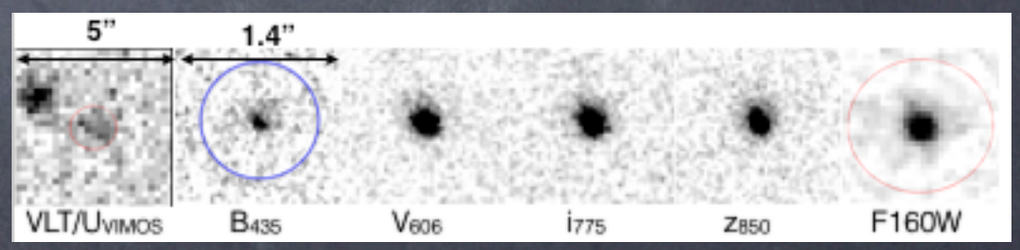
Ion1

z=3.795



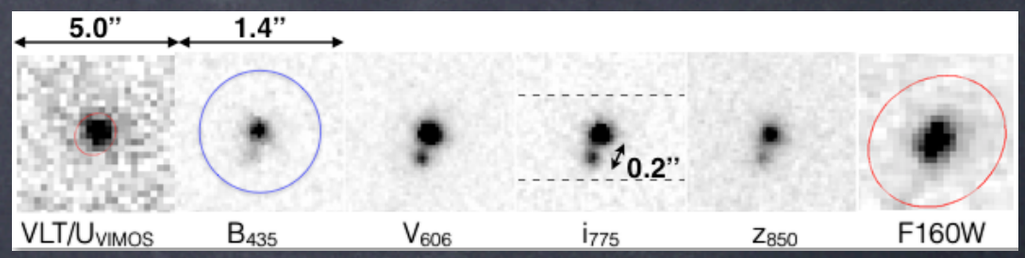
Two candidates LyC-emitters

spatially resolved Re≃250pc

HST/ACS 1500A (V15)

Ion2

z=3.213



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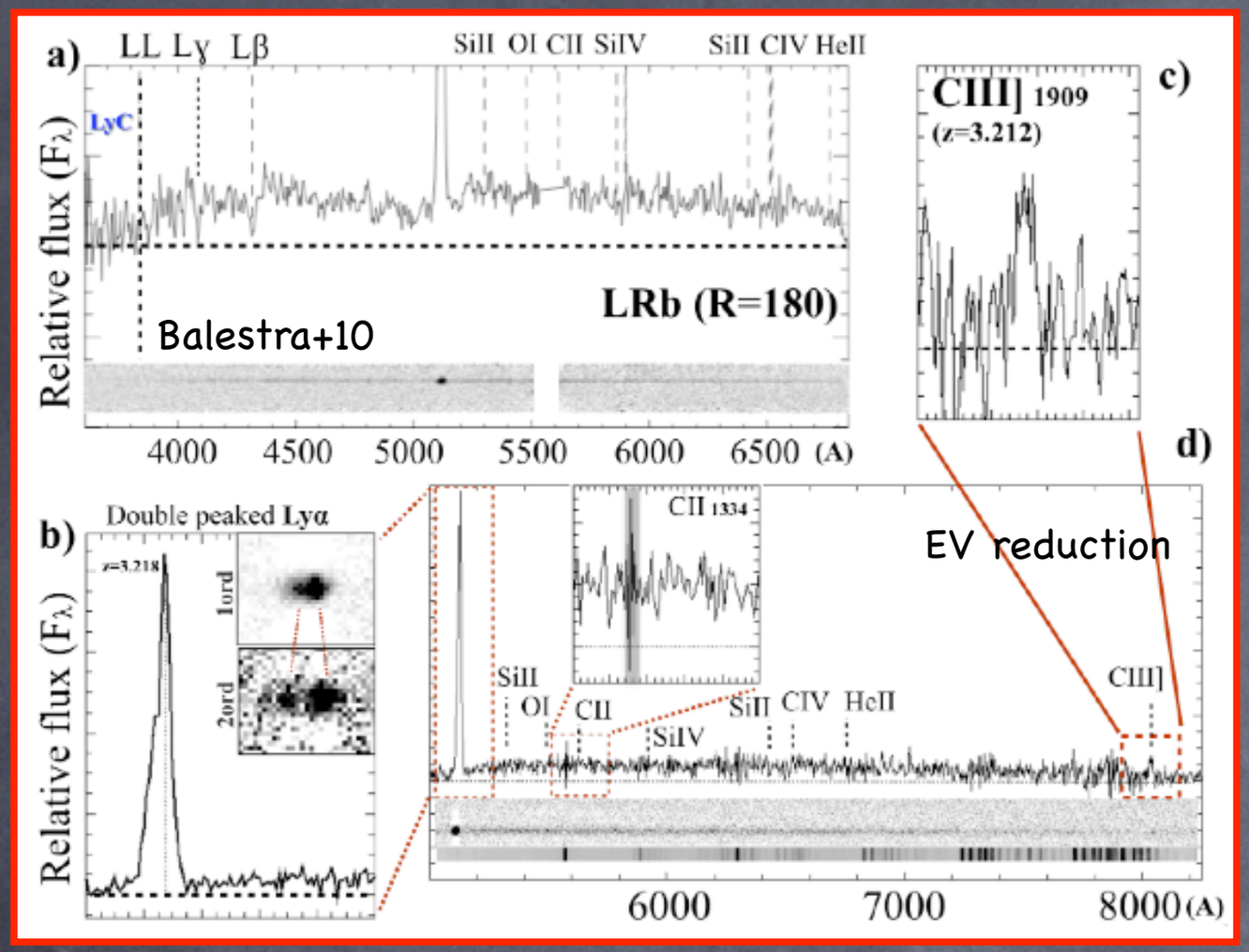
A plausible ionizer: "Ion2" (z=3.213, Re 200pc) (V15)



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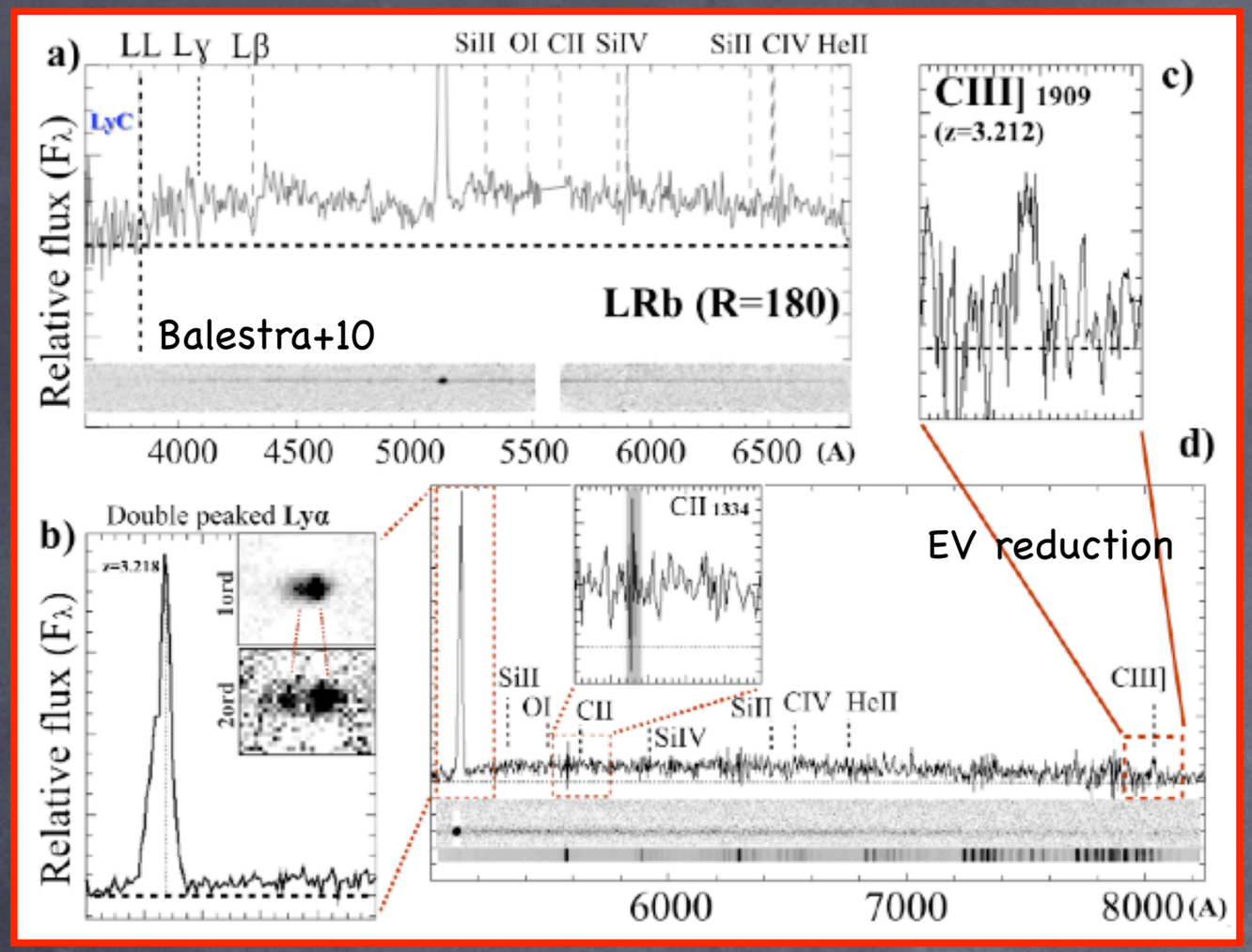

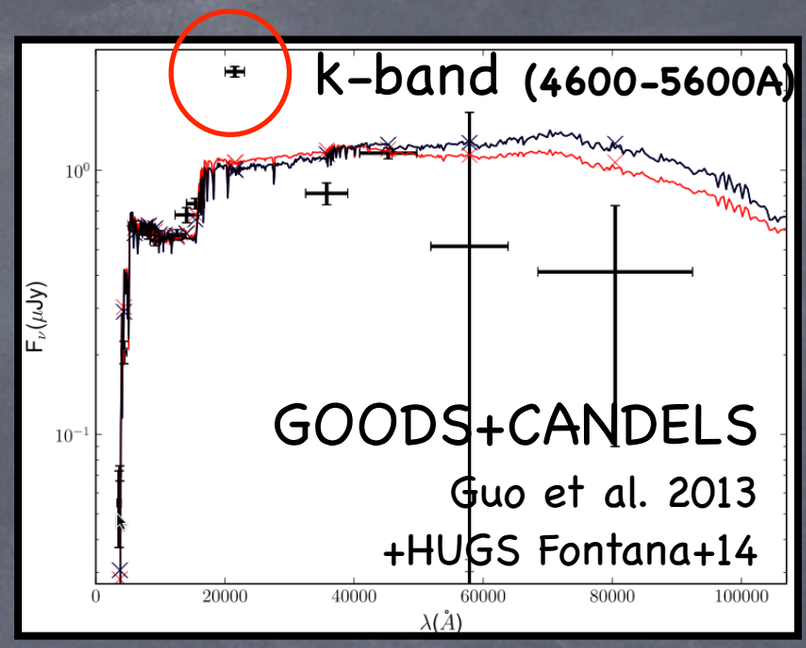

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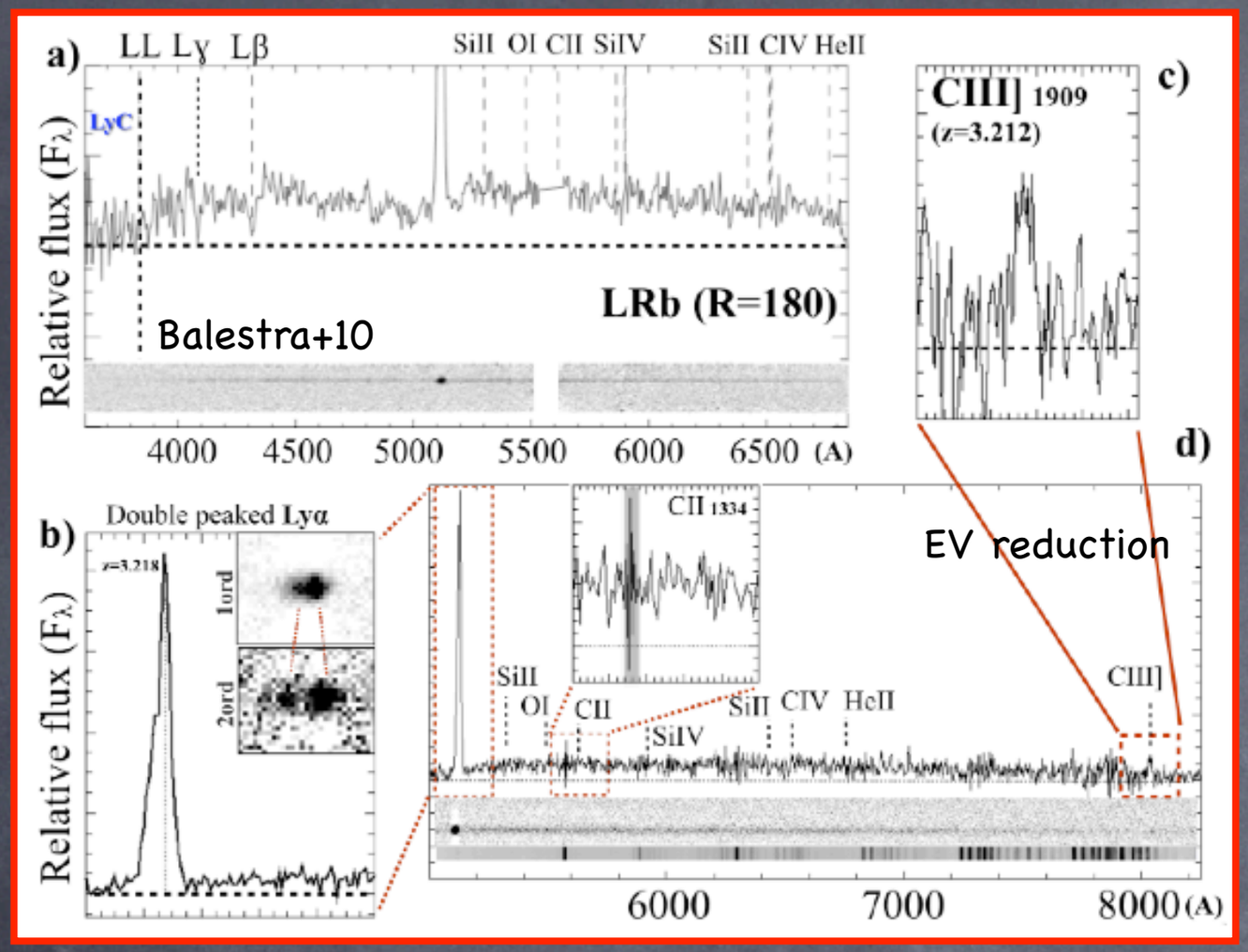

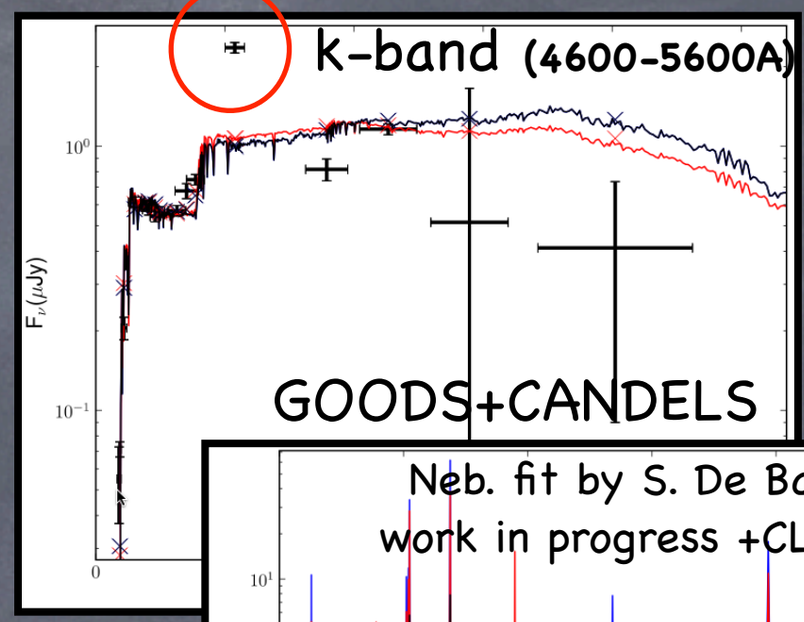

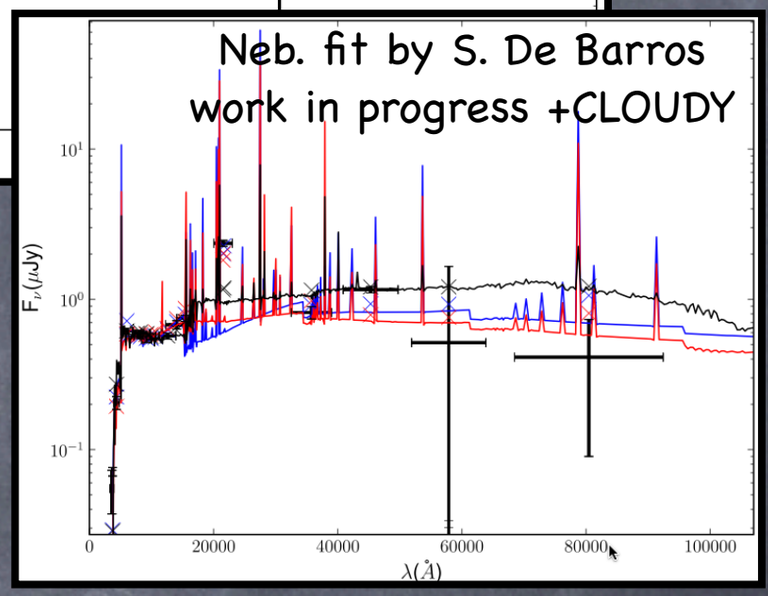

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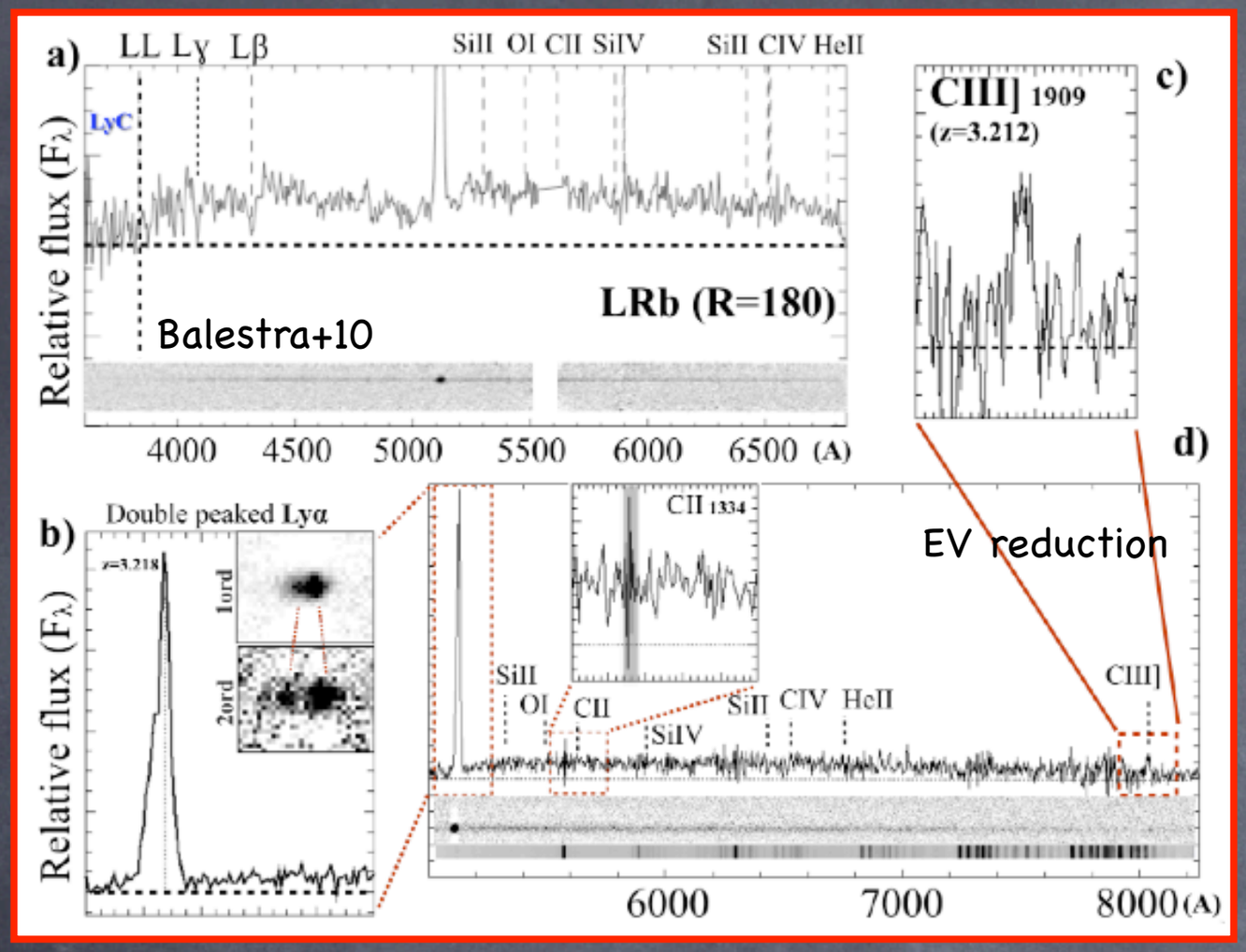

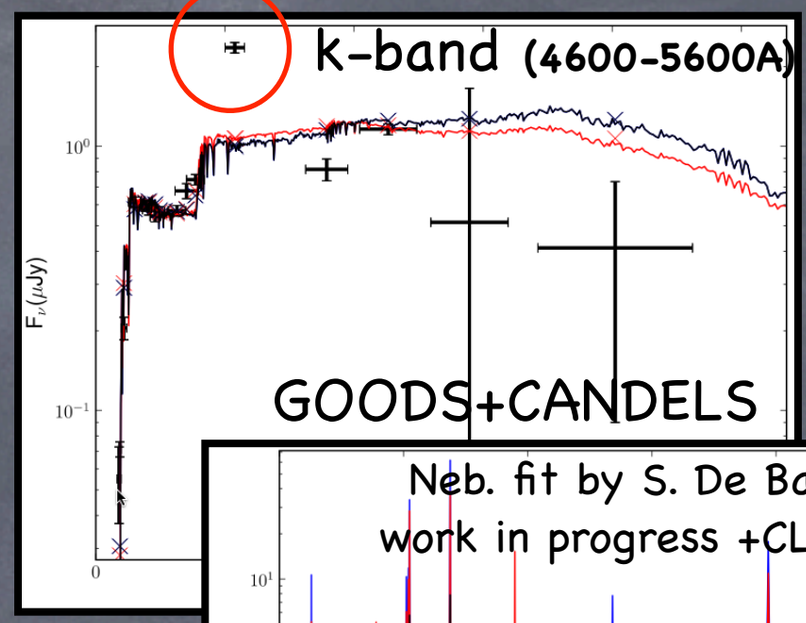

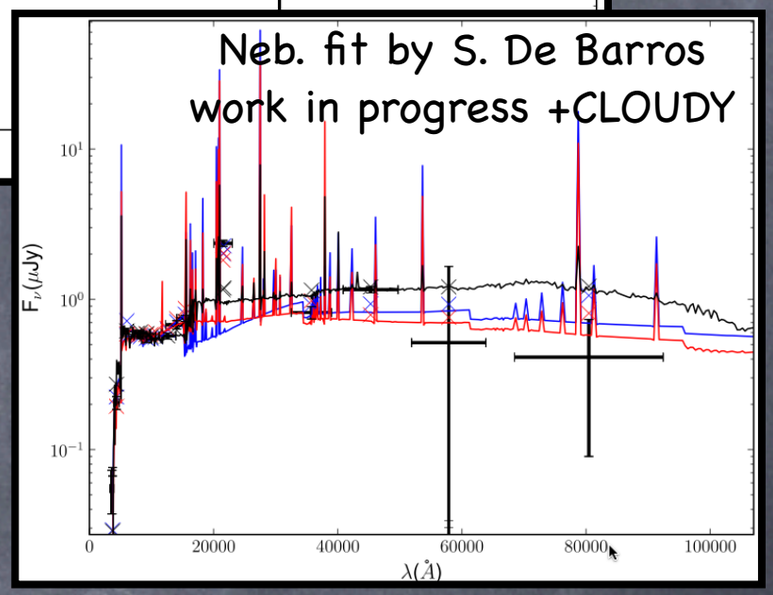

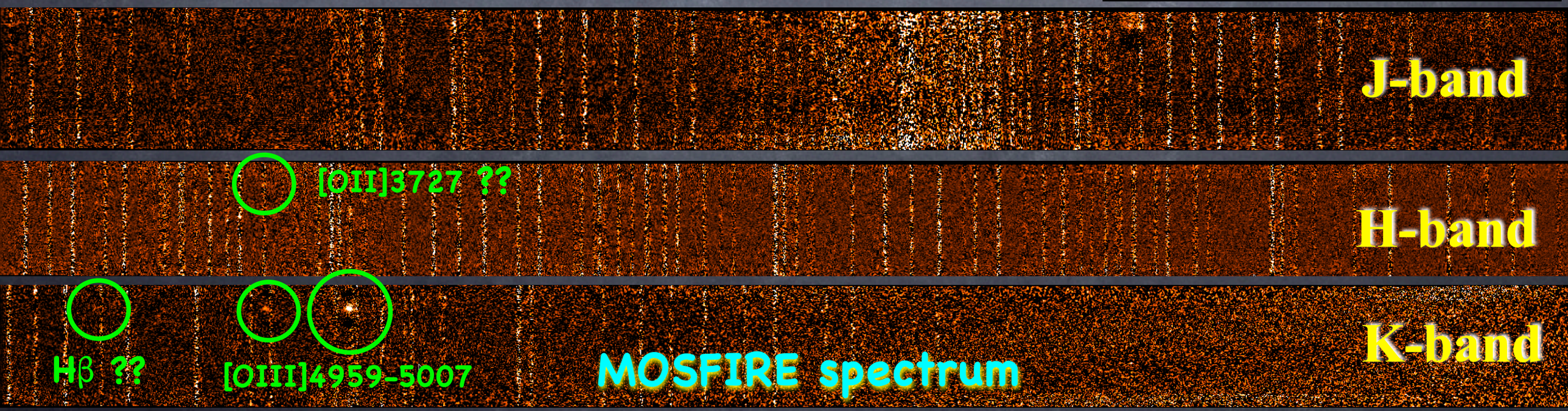

Spectrum: courtesy Jason Chu, Hyewon Suh and Guenther Hasinger

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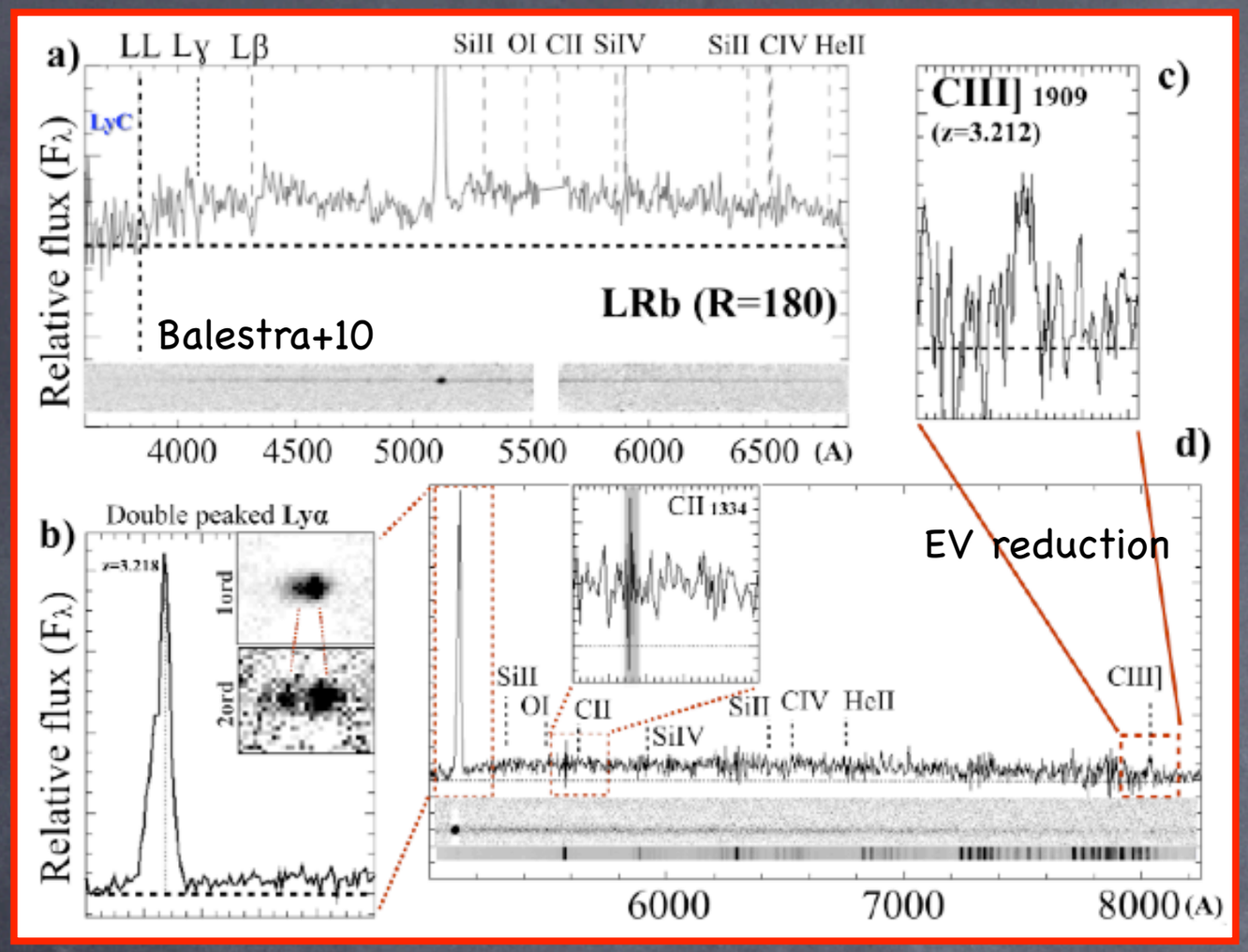

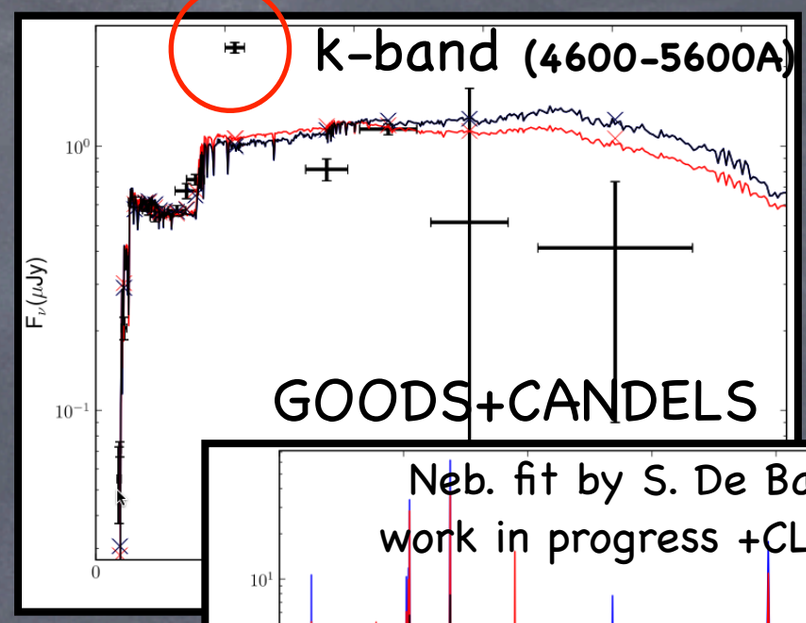

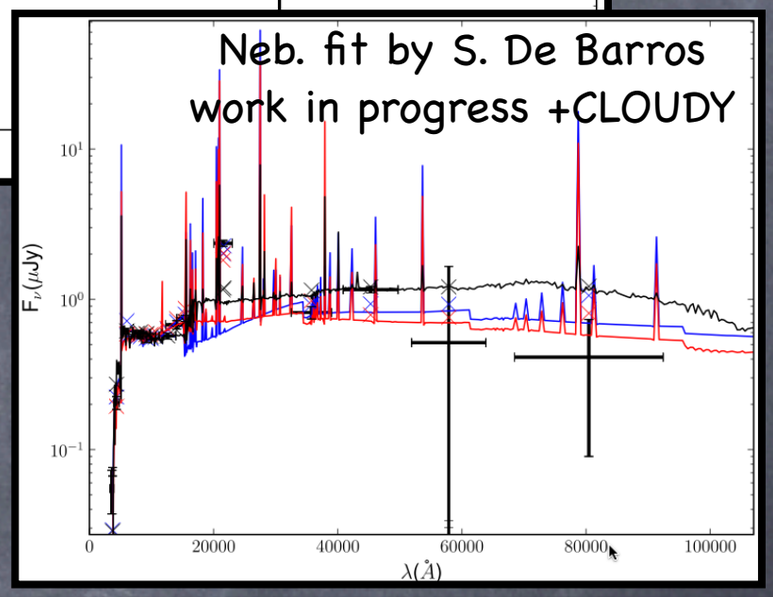

J-band

[OII]3727 ??

H-band

High ionization conditions

[OIII]/[OII]>10

[OIII]/Hb≈7-10 (Holden+14 find ≈5)

Hβ ??

[OIII]4959-5007

K-band

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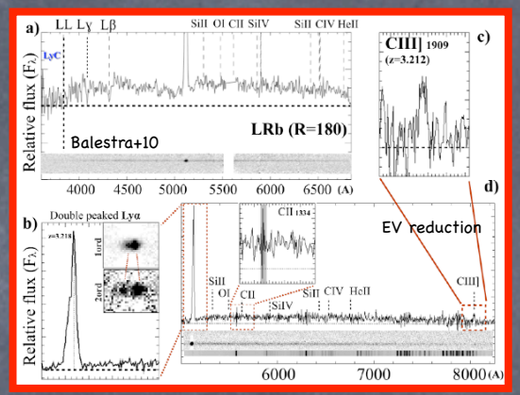

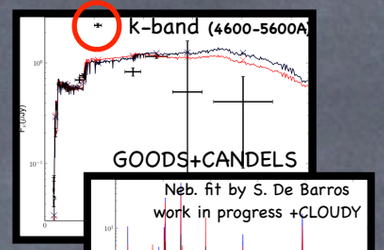

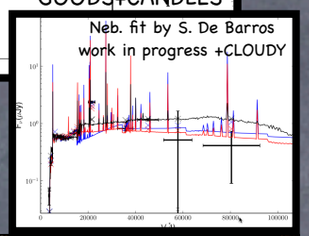

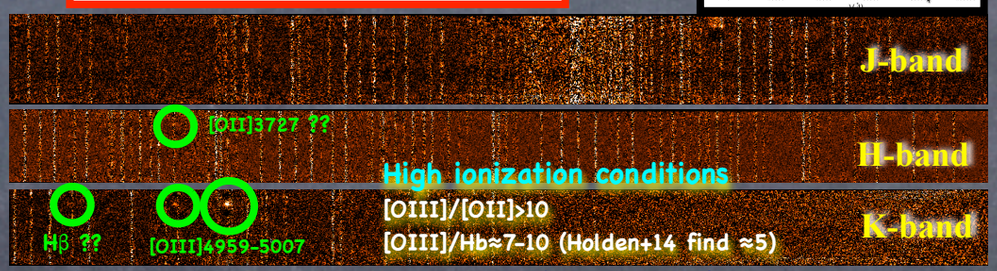

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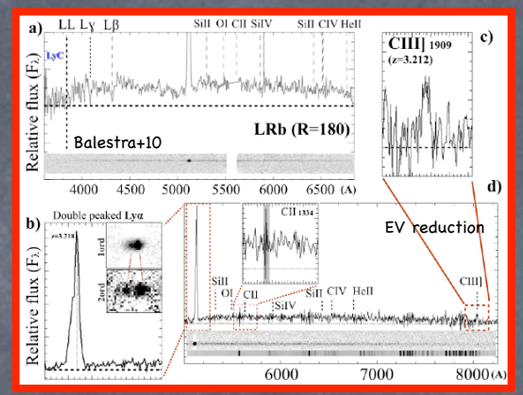

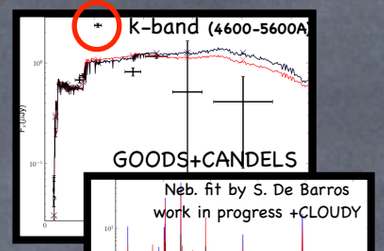

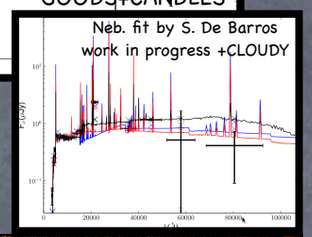

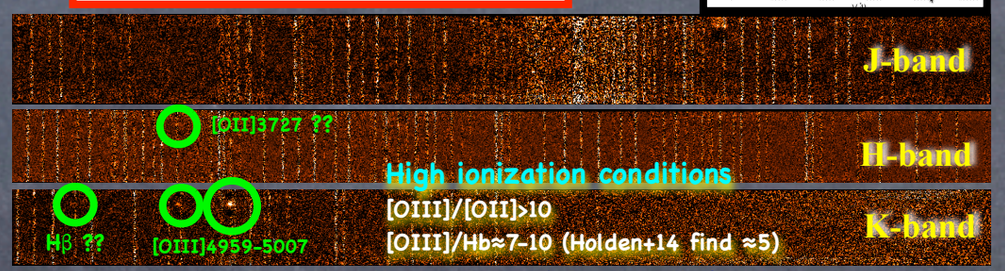

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compact SF region

Re≈250pc

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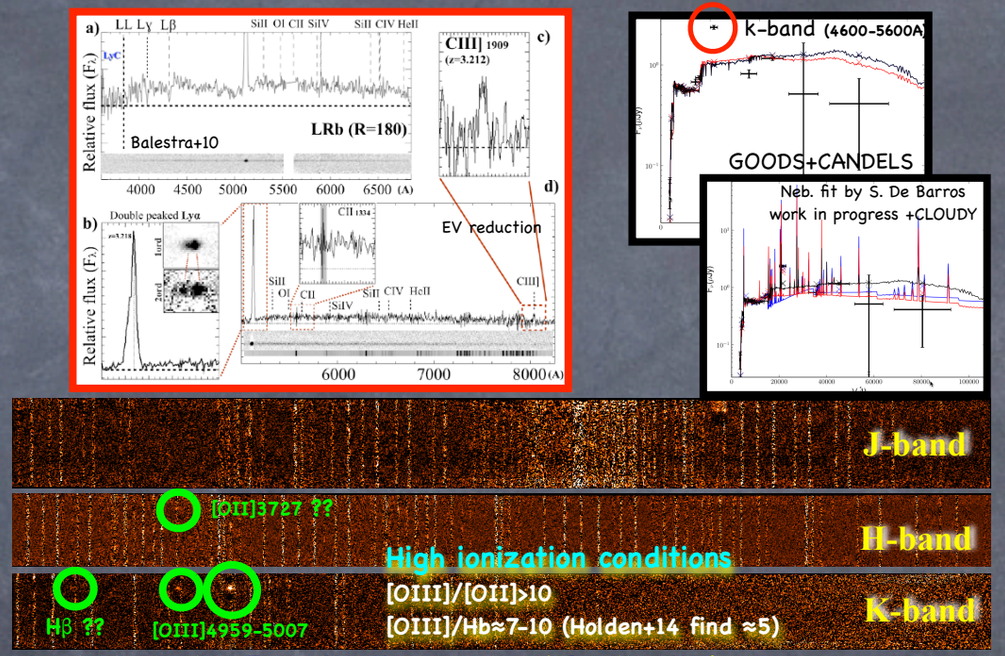

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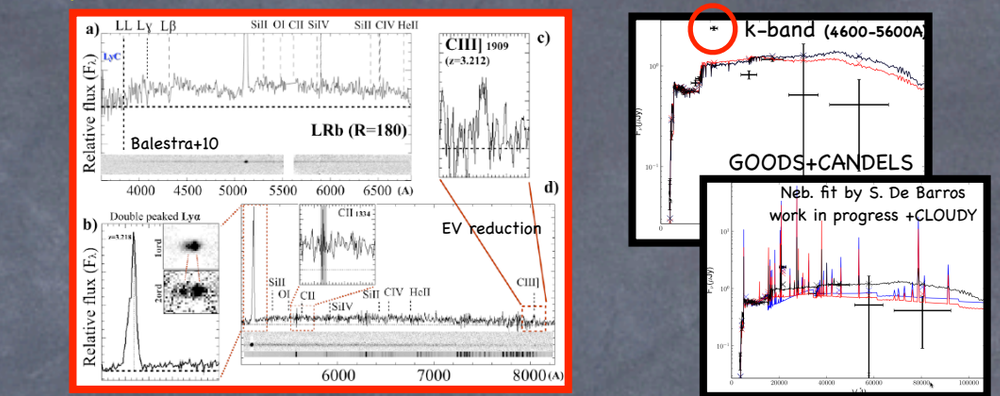

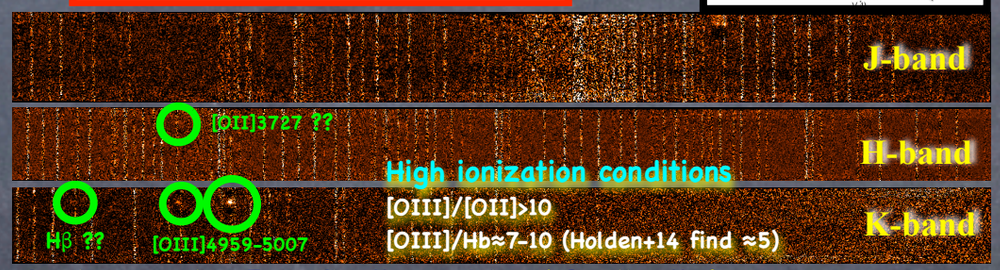

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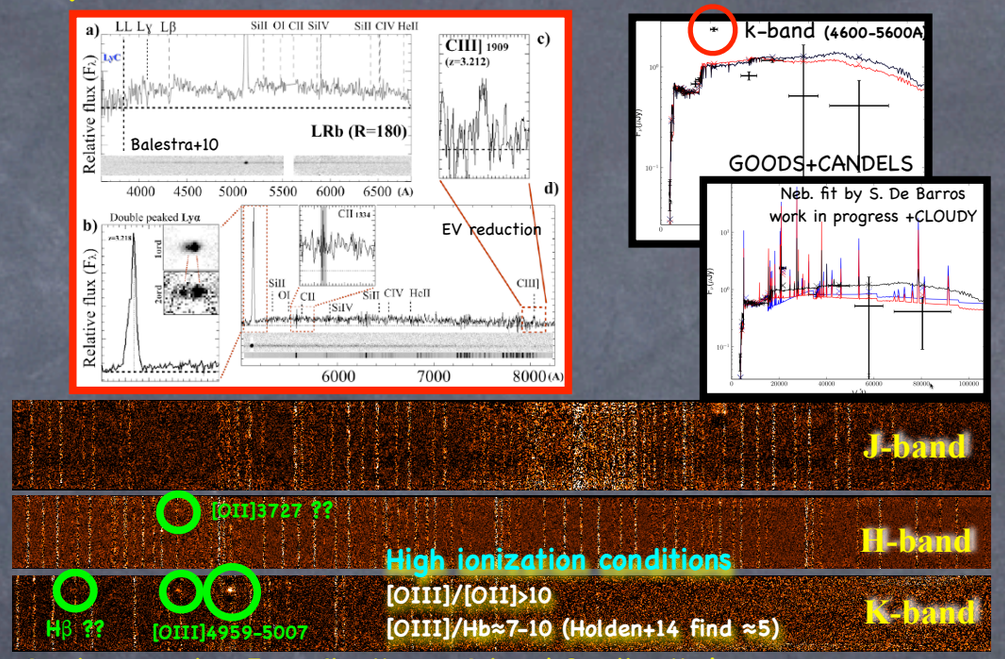

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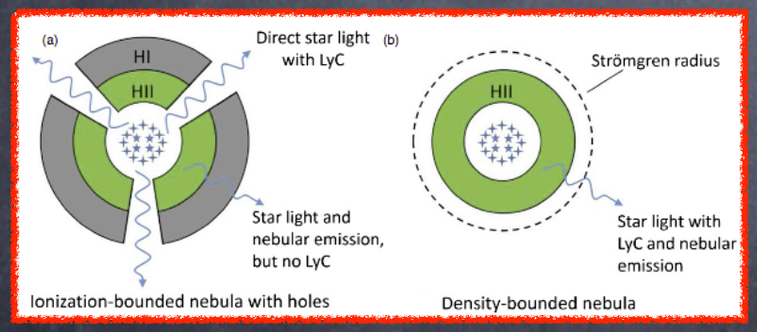
Radiation bounded

Density bounded



4) large O32 > 10!

O32=[OIII]/[OII] positively correlates (also) with **fesc** (Nakajima & Ouchi 2014; Jaskot & Oey 2013; but see Stasinska+15)

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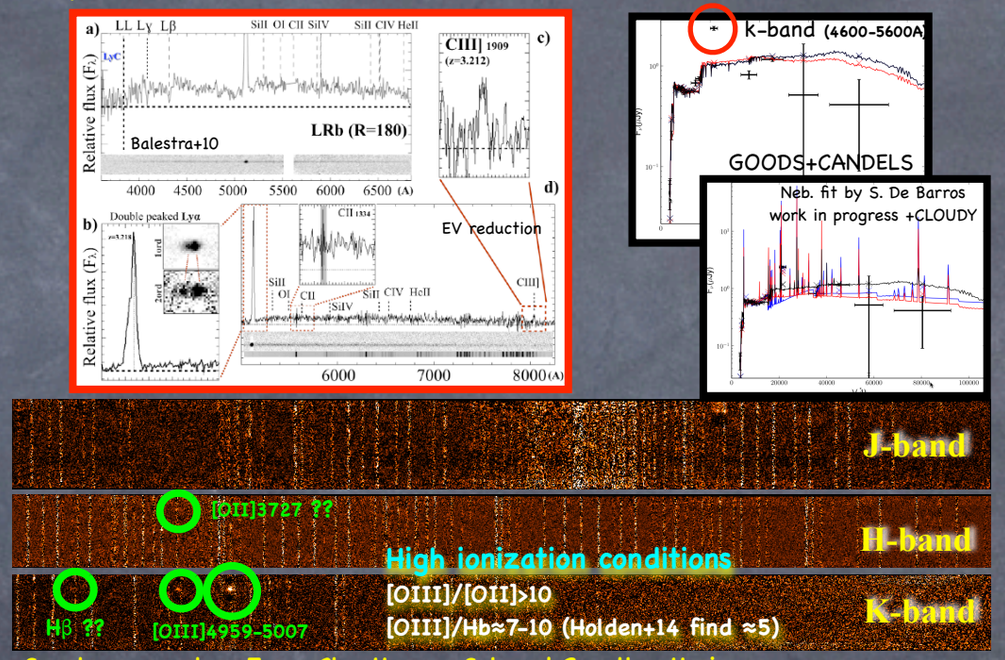

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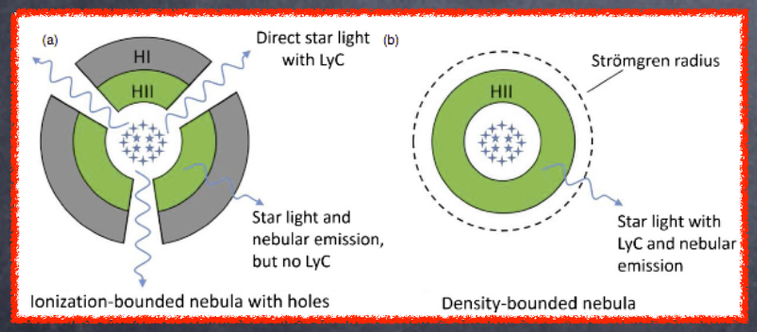

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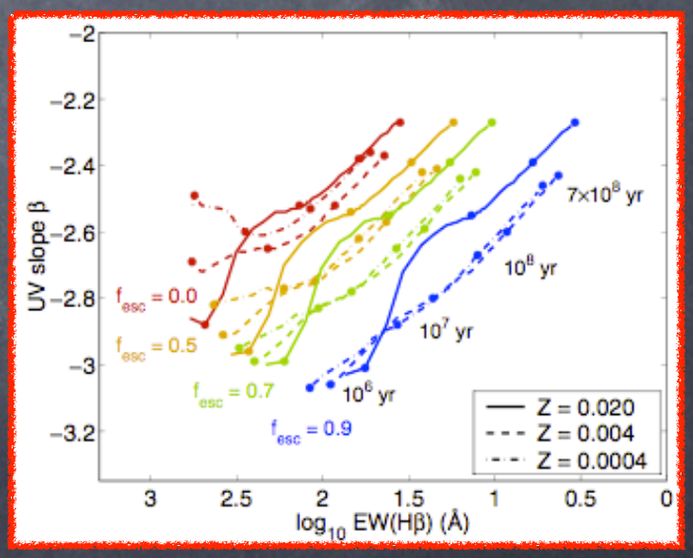
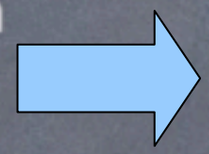


5) Blue + faint Hb equivalent **width**, linked with ionizing photons (Zackrisson+13; Inoue+11)

Coming back to the edge of the Universe, z>6

Are we closing the loop ?
not yet... however,

escape fraction of ionizing radiation



λ <912A gas abs. dust. abs

$$f_{esc} = \exp[-\tau_{H\,I,ISM}(LyC)] \times 10^{-0.4(A_{LyC})}$$

NHI dust

NHI — 1) **non-zero Lya flux** at the systemic redshift
(Schaerer+11; Berhens+14;Verhamme+14)

Covering fraction — 2) weak Carbon Silicon **low-ionization absorption lines** (CII,SiII), low covering fraction (Jones+14; Heckman+11)

Density bounded nebula ? — 3) **large O32**=[OIII]**4959-5007** / [OII]**3727 > 10!**
O32 index positively correlates (also) with fesc
(Nakajima & Ouchi 2014; Jaskot & Oey 2013;but see Stasinska+15)

∝(1-fesc) — 4) Blue + **faint Hb equivalent width**, linked with ionizing photons (Schaerer+02; Zackrisson+13; Inoue+11)

Merging — 5) **Merging** may trigger high Lya and LyC fesc (e.g., Rauch+11)

Conclusions

The search of redshift 6 and 7 galaxies:

Large sample at z≈6 (>100 sources) with deep spectroscopy (15-30hr @ VLT) homogeneously selected, H-band based:

➔ Relevant to study **physical properties** (SED fit, stack, etc.) in progress.

➔ Reionization epoch with **Lya demography** (next talk)

Lyman continuum leakage:

New results from lower-z (z≈3-4) LyC candidates:

➔ candidates LyC emitters can be selected from UV colors (Vanz+15)

➔ LyC leakage linked to Lya structure, NHI covering fraction, morphology, optical nebular emission lines (Verhamme+14;Nakajima+14;Heckman+11…).

➔ "Ion2" Optical (VIMOS) + NIR (MOSFIRE) spectra + HST imaging seem to support the LyC leakage.

At z>6 the UV continuum will be probed with ELT and (rest-frame)optical spectroscopy with both **JWST** and **ELT**