

Understanding cosmic reionization with deep spectroscopy

The early growth of galaxies: The HST, Spitzer and Herschel joint legacy - Sexten Center for Astrophysics



Stephane De Barros - Eros Vanzella
INAF OABO

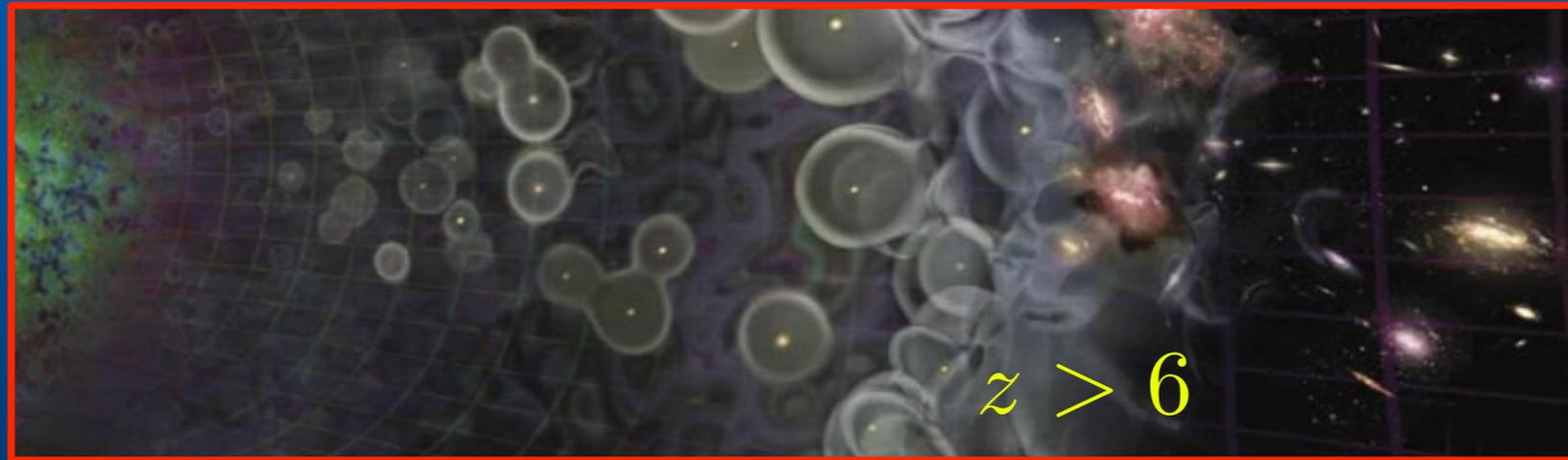


Main collaborators:

L. Pentericci, A. Fontana, M. Giavalisco, A. Grazian, M. Castellano, R. Amorín, B. Siana and more

Some constraints on the HI cosmic reionization

- Reionization epoch: from “dark ages” to “light”



- When, how, who:

$$z, \Delta z \quad \frac{dQ_{\text{HII}}}{dt} \quad \text{star-forming galaxies, AGNs, ... ?}$$

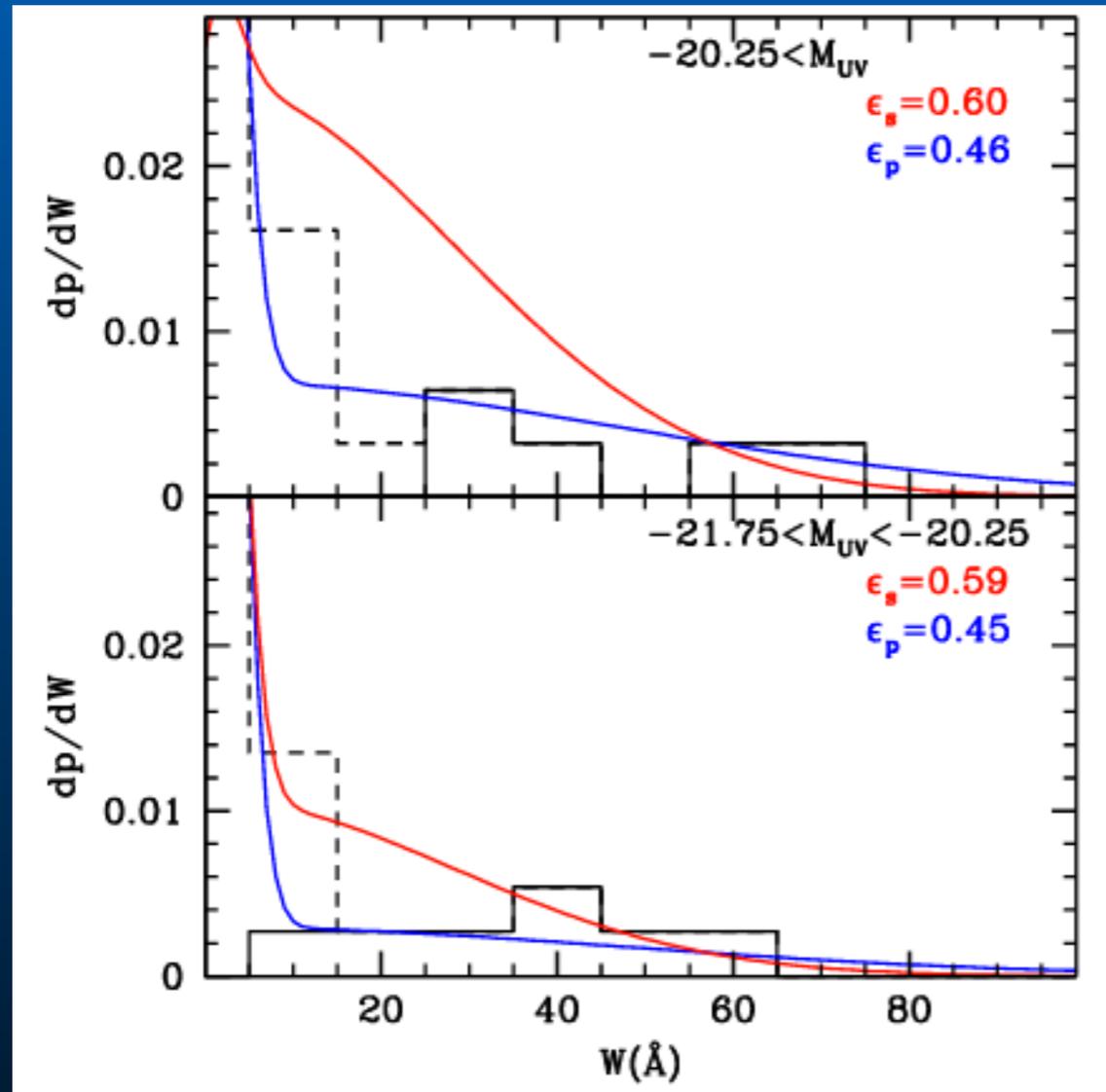
Some hints...

When - reionization has affected the CMB (Thomson scattering):

$$z_r = 8.8^{+1.3}_{-1.2} \text{Planck+15}$$

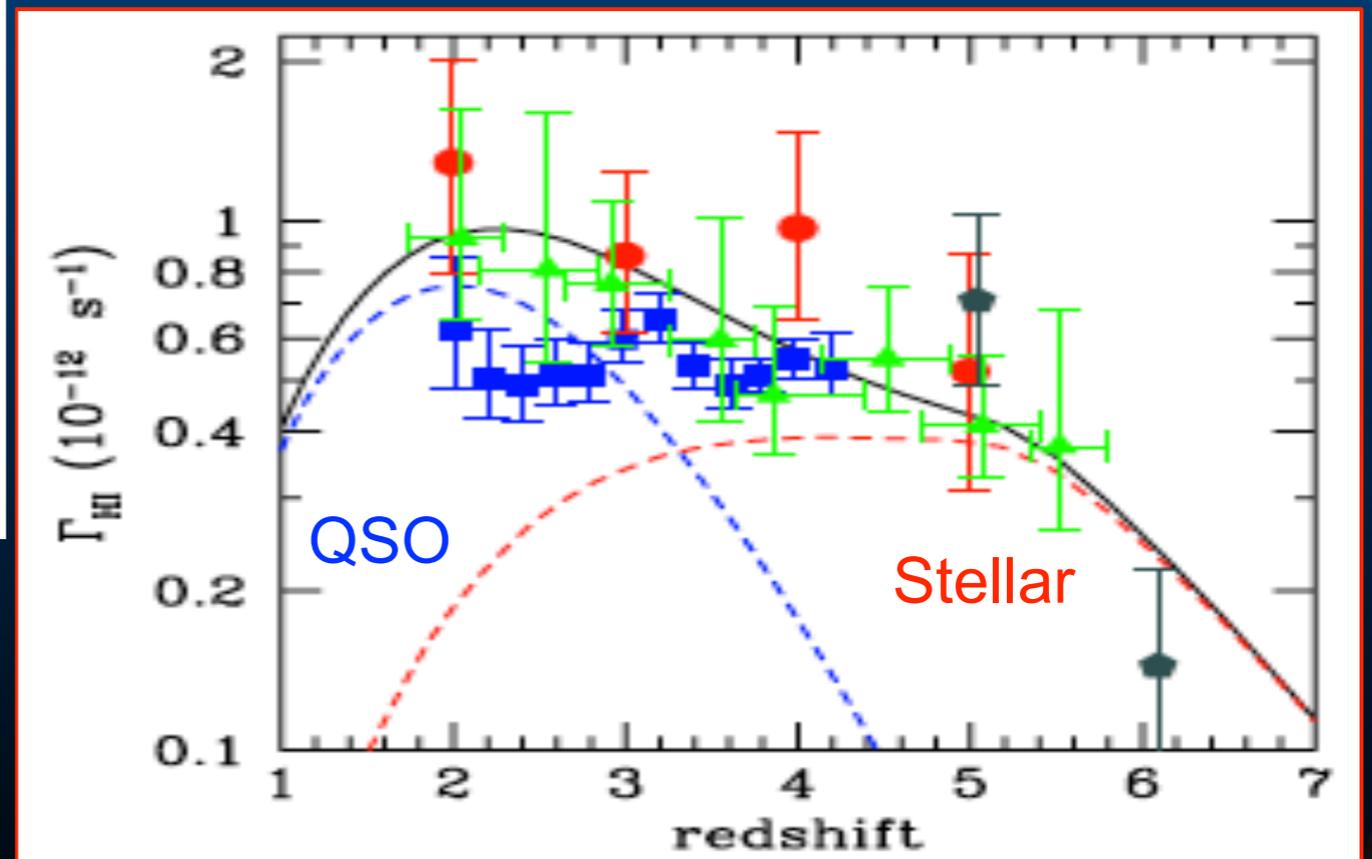
Some constraints on the HI cosmic reionization

How: patchy vs. smooth



Pentericci+14

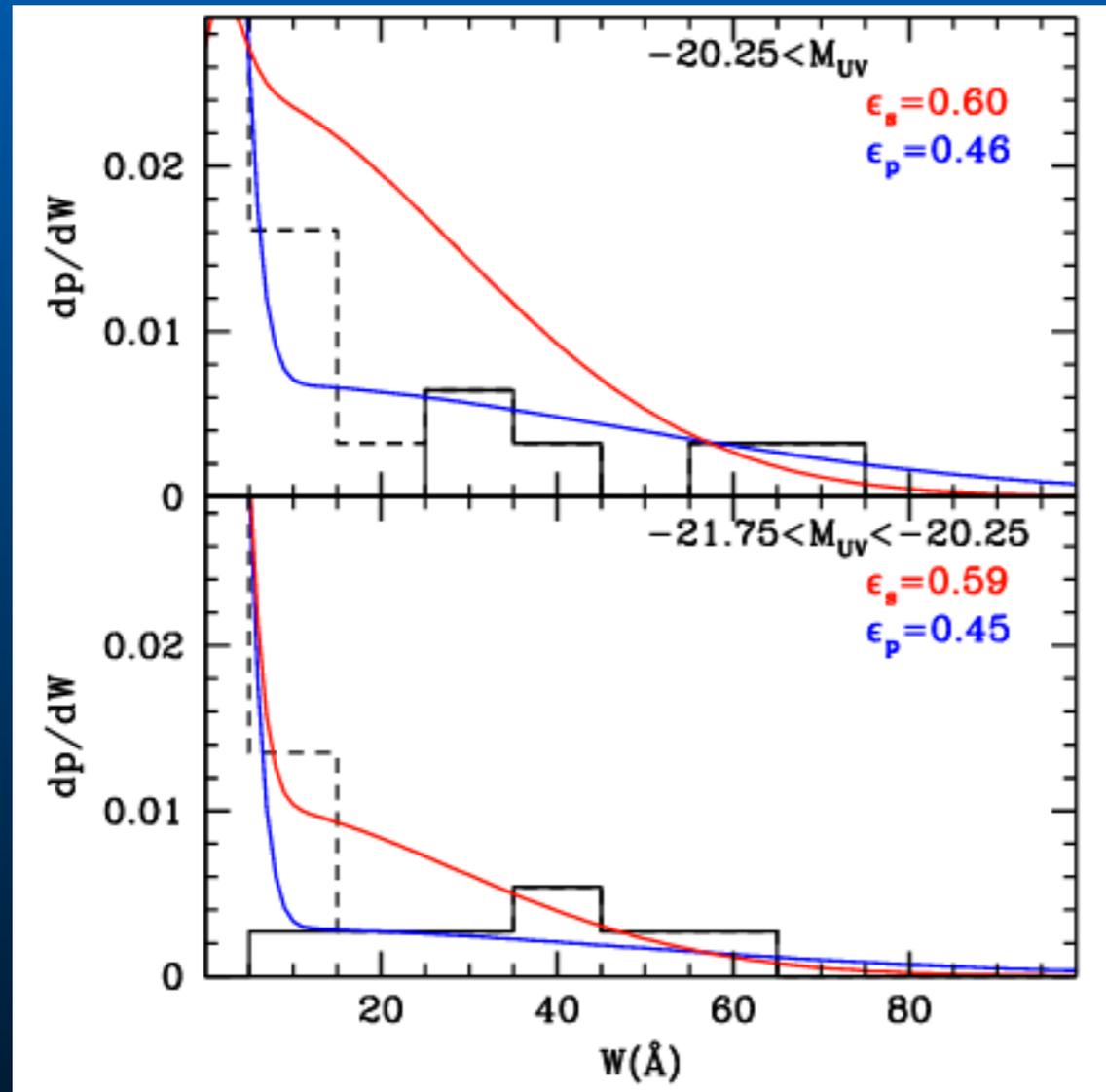
Haardt & Madau 2012



Who: star-forming galaxies vs. AGNs

Some constraints on the HI cosmic reionization

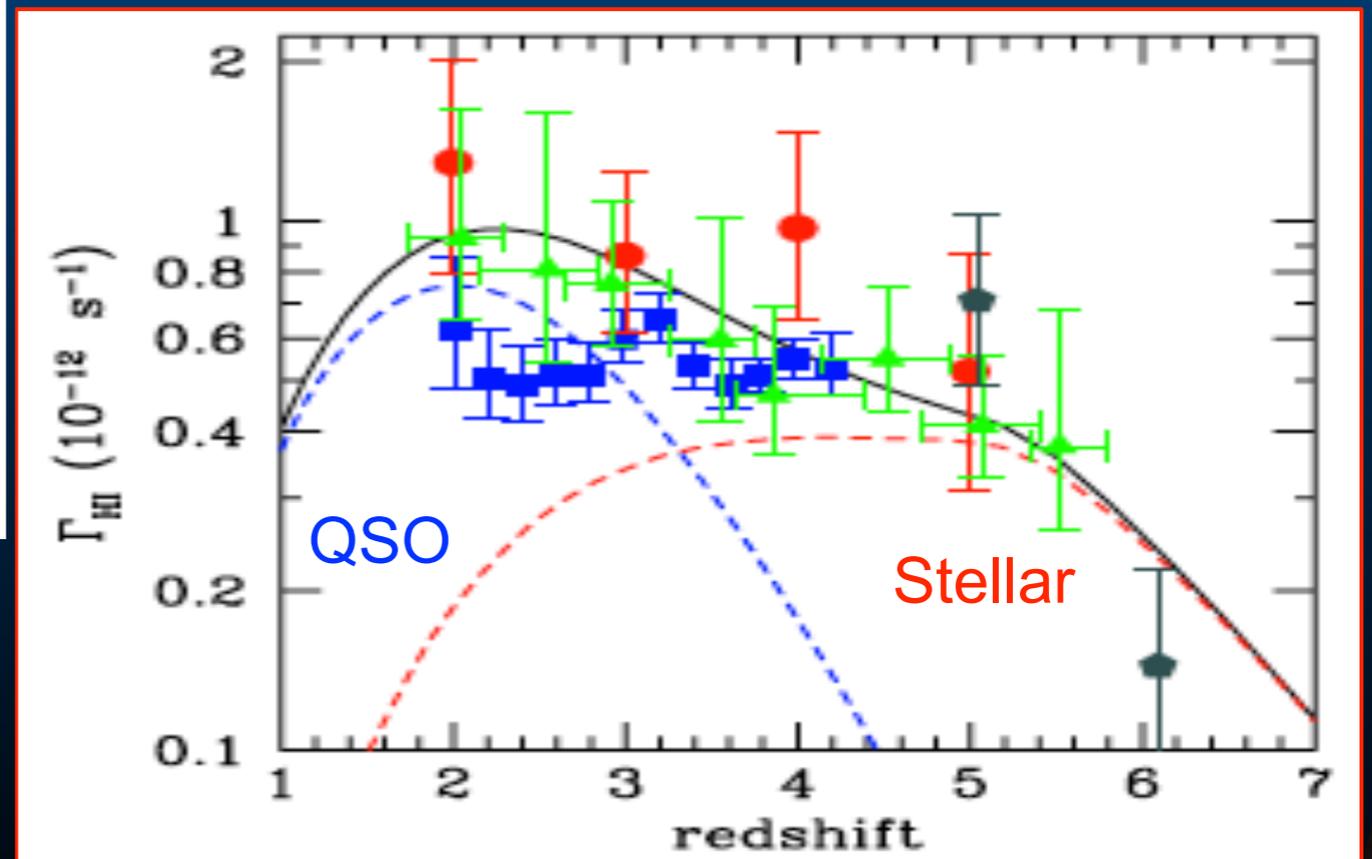
How: patchy vs. smooth



Pentericci+14

But... faint AGNs?
Madau & Haardt 2015
Giallongo+2015
Fiore+2012

Haardt & Madau 2012



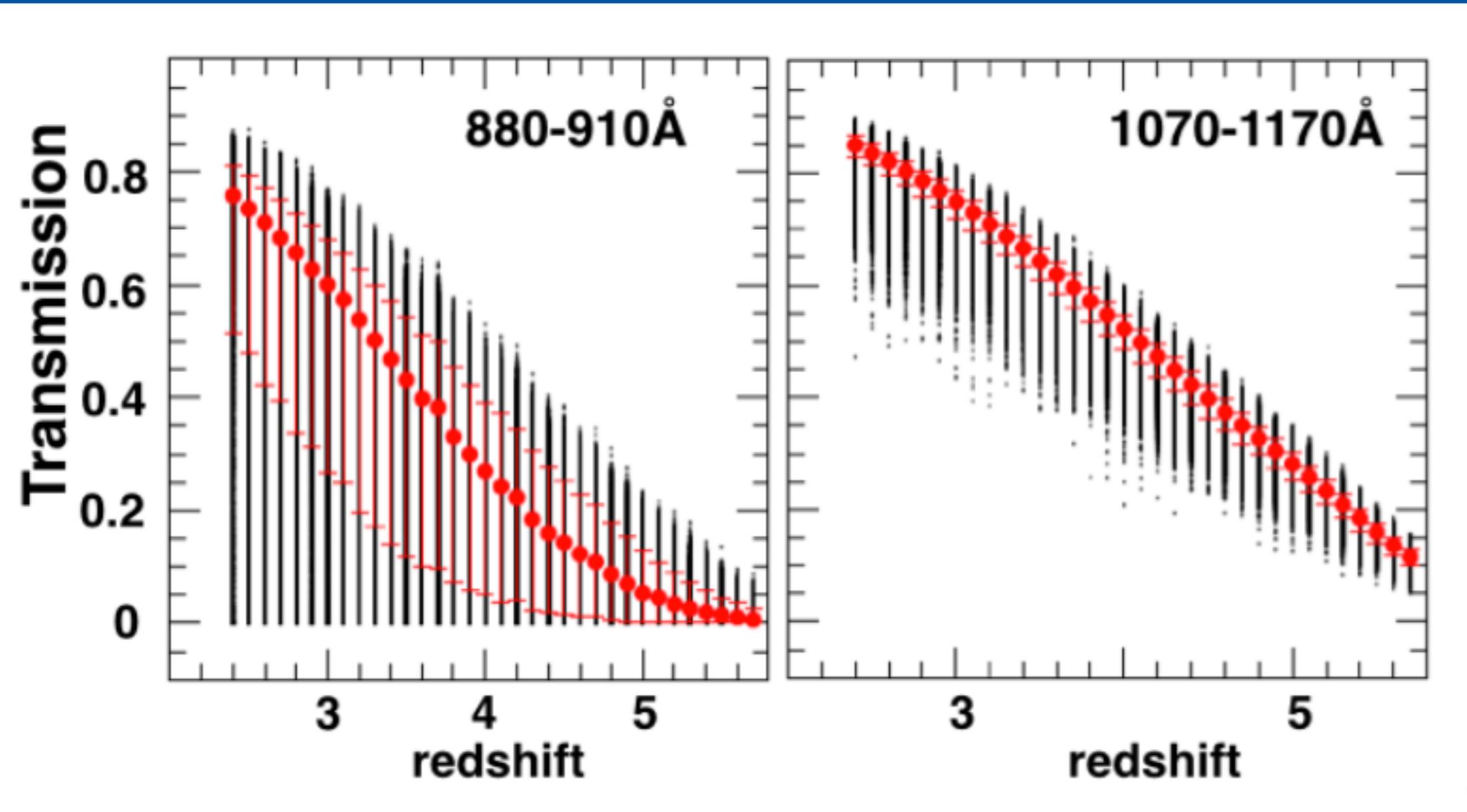
Who: star-forming galaxies vs. AGNs

Understand cosmic reionization: looking at the sources (and their analogs)

1. Edge of cosmic reionization: FORS2 large program + archives (see L. Pentericci & M. Castellano talks)
2. Search for Lyman continuum emitter at high-redshift... but not too high

Understand cosmic reionization: looking at the sources (and their analogs)

1.
a
2.
b



Vanzella+15, Inoue+08, Inoue 2014

Spectroscopic search for $z \sim 6$ galaxies

- VLT/FORS2 Large program (PI: L. Pentericci)

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 program (PI: A. 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 program (PI: A. Bunker, archive)

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

Final sample (+ Vanzella+09):

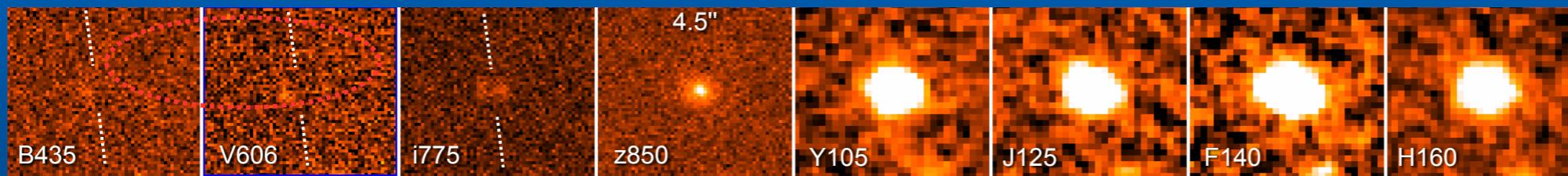
~100 $z \sim 7$ galaxies (Pentericci & Castellano talks)

~200 $z \sim 6$ galaxies

6 to 30 hr integration time each

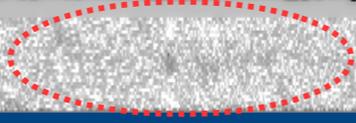
Homogeneously selected (H-band based)

Spectroscopic search for $z \sim 6$ galaxies



$z = 6.108, \beta = -1.99 \pm 0.09$

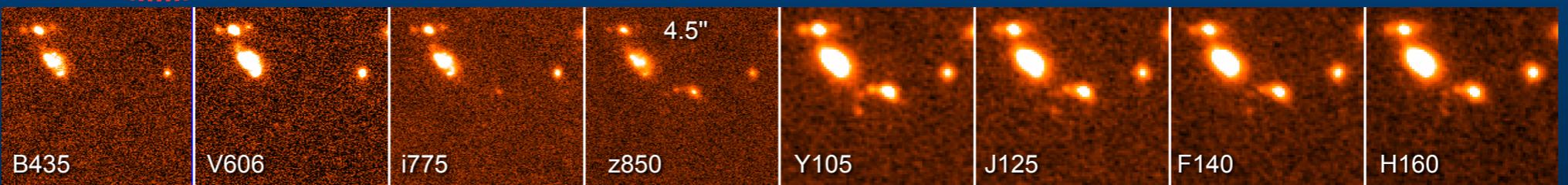
(30hr VLT/FORS2)
EW(Lya)=9A



$z = 5.938, \beta = -1.88 \pm 0.08$

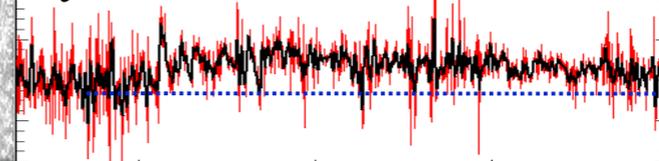
EW(Lya)=7A

(30hr VLT/FORS2)



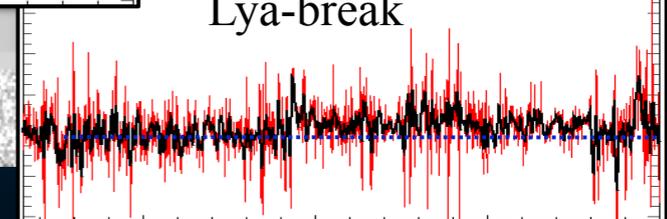
BDF5870,
 $z = 5.632,$
 $\beta = -1.38 \pm 0.14$
 $m_{1500} = 24.88$

Ly-alpha-break



15443,
 $z = 5.938,$
 $\beta = -1.88 \pm 0.08$
 $M_{1500} = 25.77$

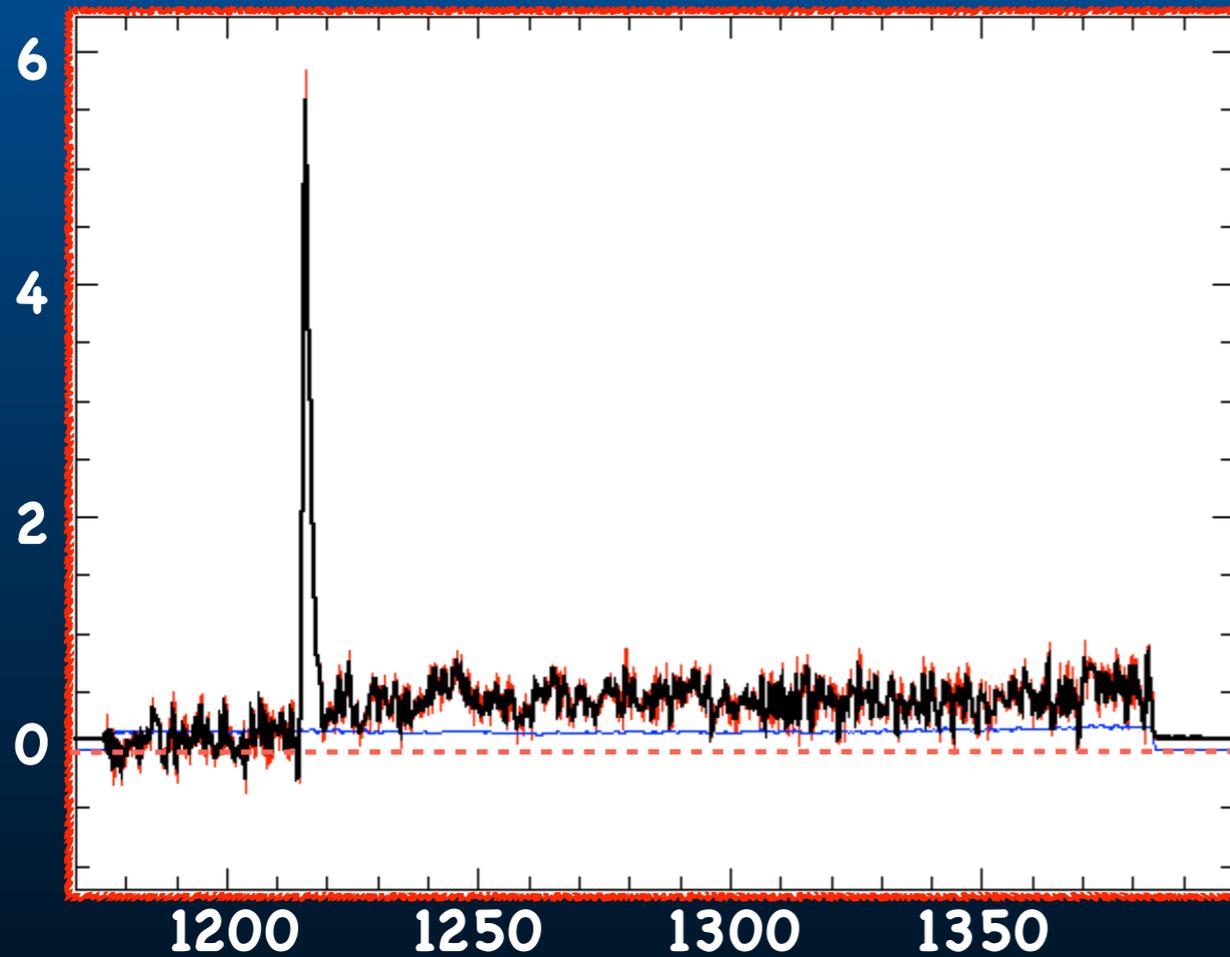
Ly-alpha-break



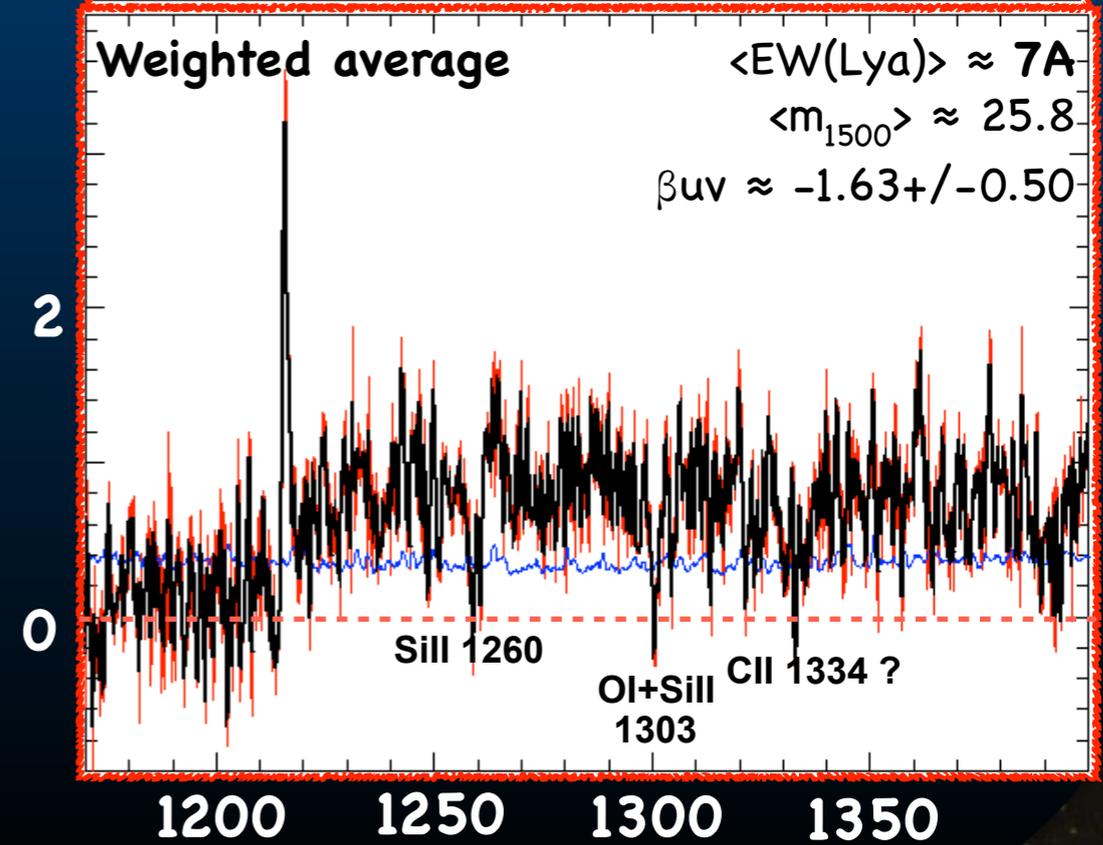
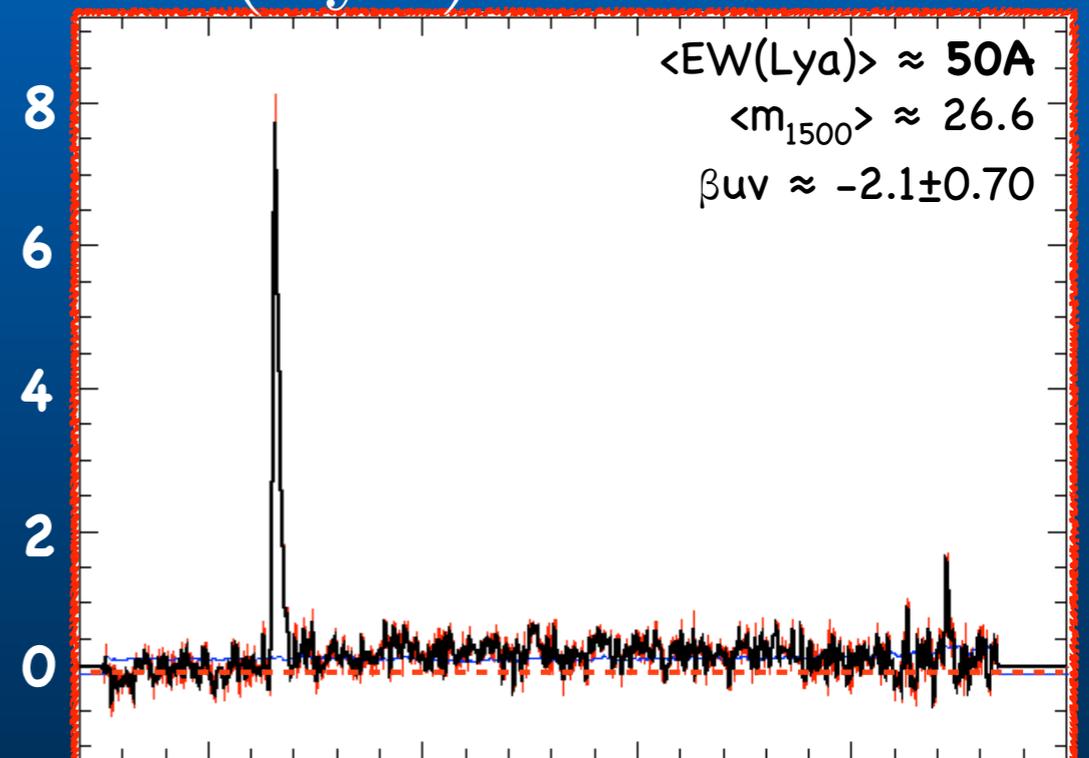
Allow to exclude low- z contamination

Spectroscopic search for $z \sim 6$ galaxies

740 hr VLT/FORS full sample



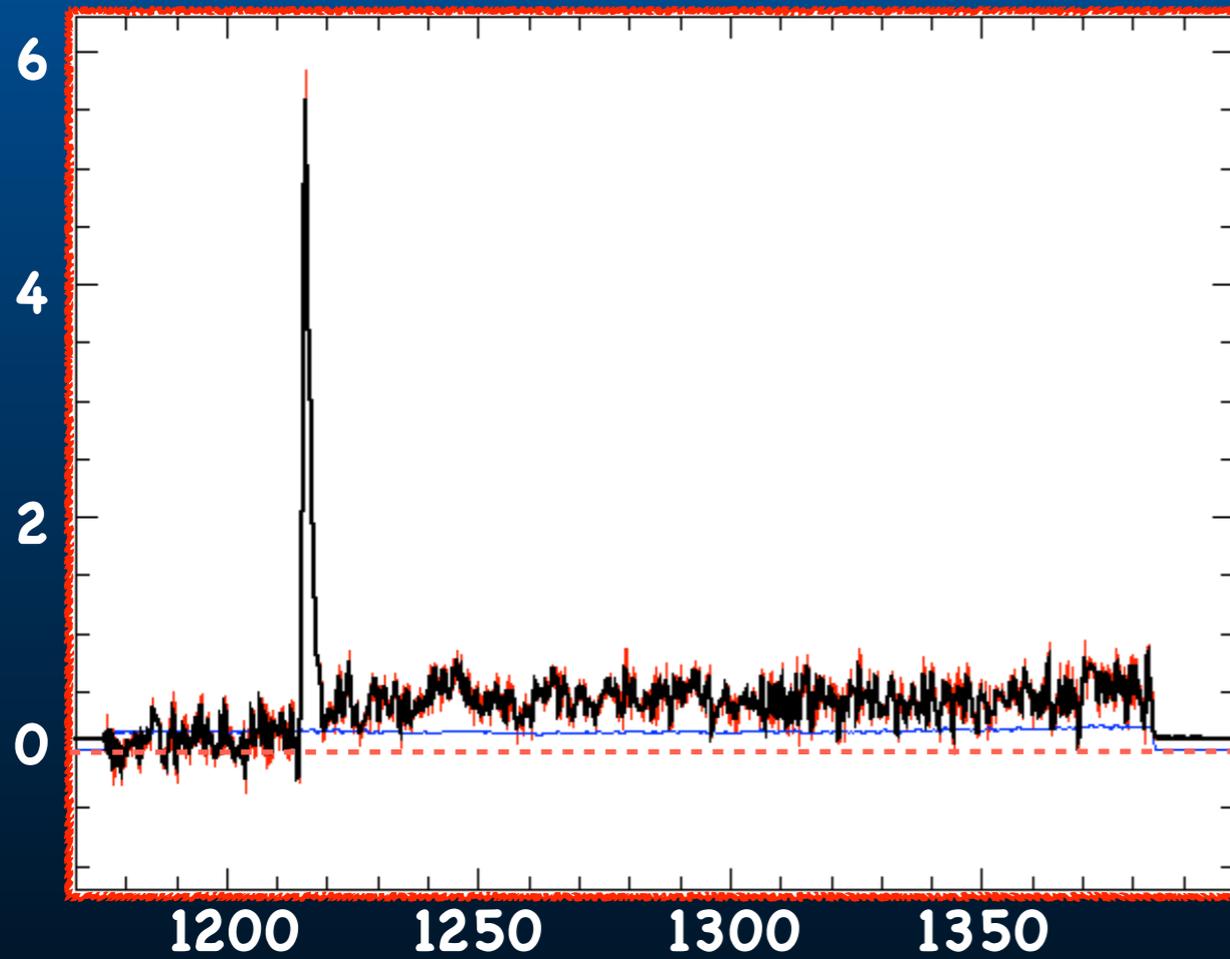
$EW(Ly\alpha) > 20\text{\AA}$



$EW(Ly\alpha) < 20\text{\AA}$ (200 hr)

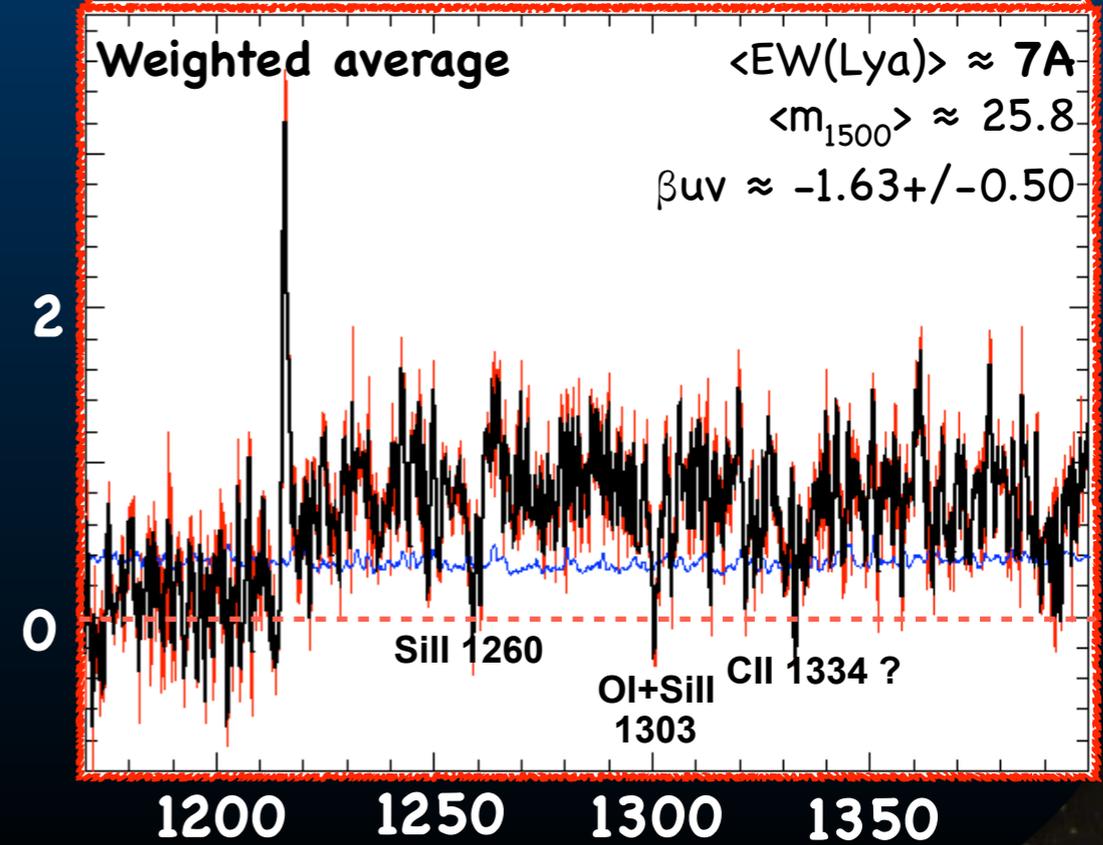
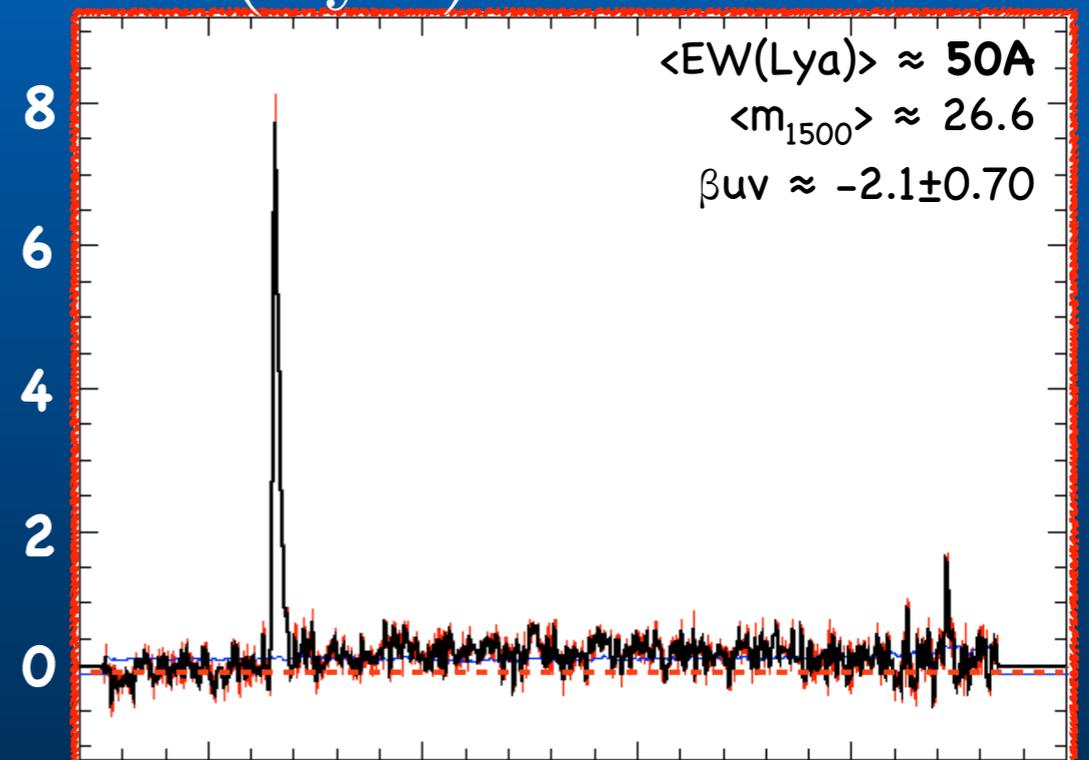
Spectroscopic search for $z \sim 6$ galaxies

740 hr VLT/FORS full sample



Vanzella+16 in prep

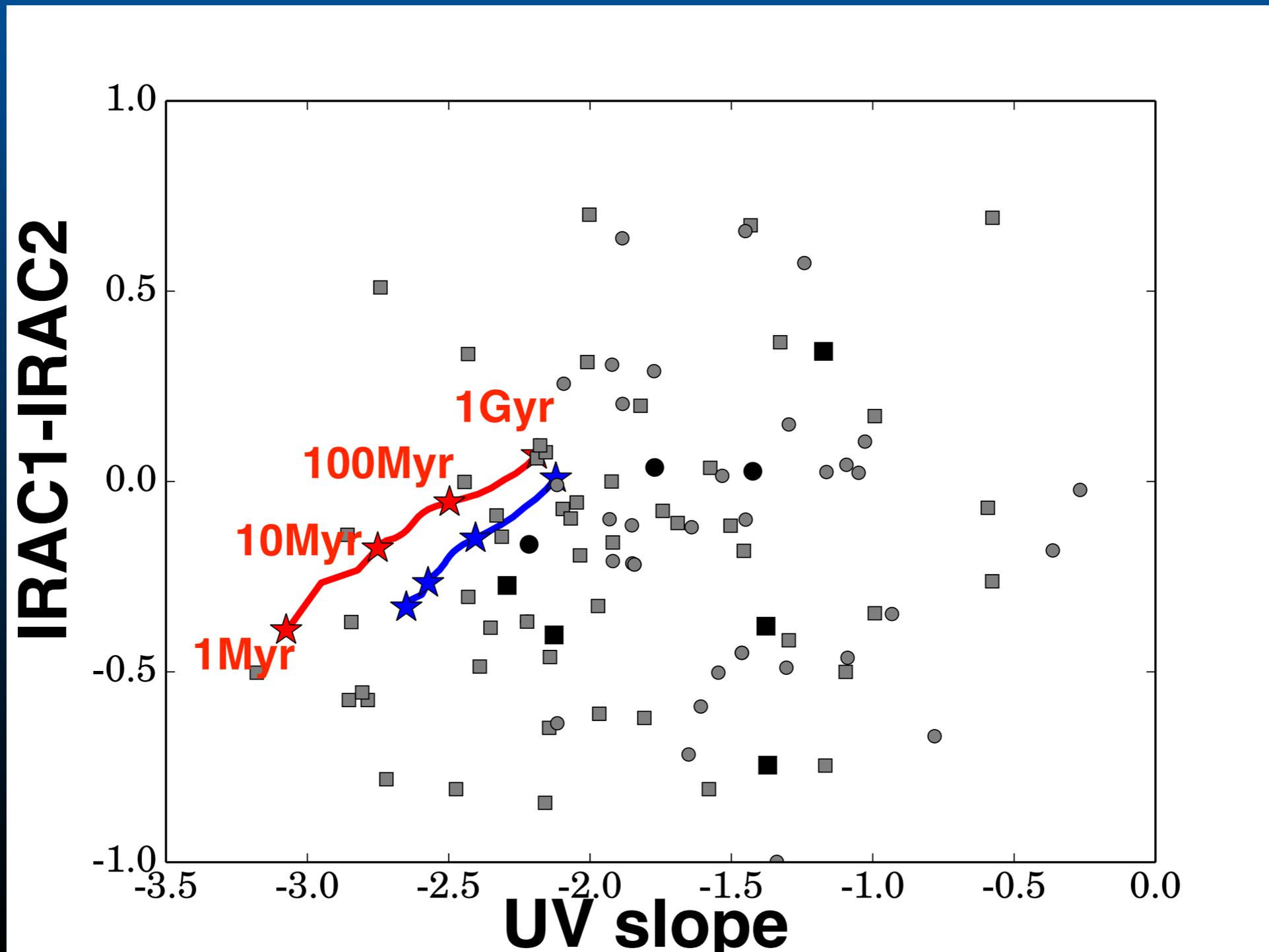
$EW(Ly\alpha) > 20\text{\AA}$



$EW(Ly\alpha) < 20\text{\AA}$ (200 hr)

Galaxy physical properties at the edge of the cosmic reionization

Can we say something about the strength of the lines at $z \sim 6$?



34 ?

Galaxy physical properties at the edge of the cosmic reionization

UV slope

very degenerate: age+dust+metallicity+SFH

but blue slopes interesting (=young age, low metallicity, no dust)

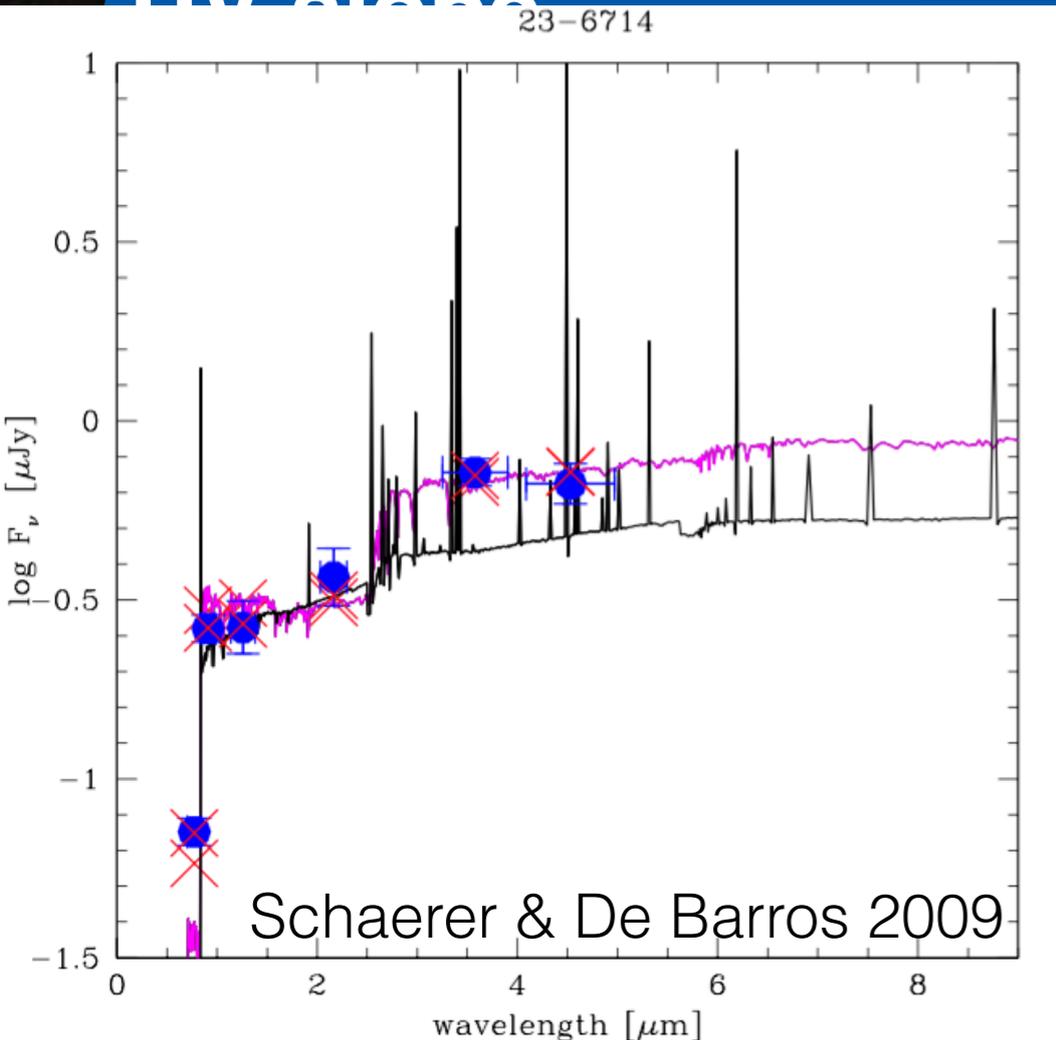
SED fitting: rely on assumptions (SFH, dust attenuation curve, IMF, ...) + IRAC1 and 2 channels affected by emission lines (Talks: Marmol-Queralto, Capak, Labbe, Castellano)

We use a SED fitting tool and a set of assumptions well tested against high-z galaxies

Schaerer & De Barros 2009, 2010, Schaerer+2013, De Barros+2014, Sklias+2014, De Barros+2016

Exploring a parameter space as large as possible (see C. Pacifici talk)

Galaxy physical properties at the edge of the cosmic reionization



+dust+metallicity+SFH
sting (=young age, low metallicity,

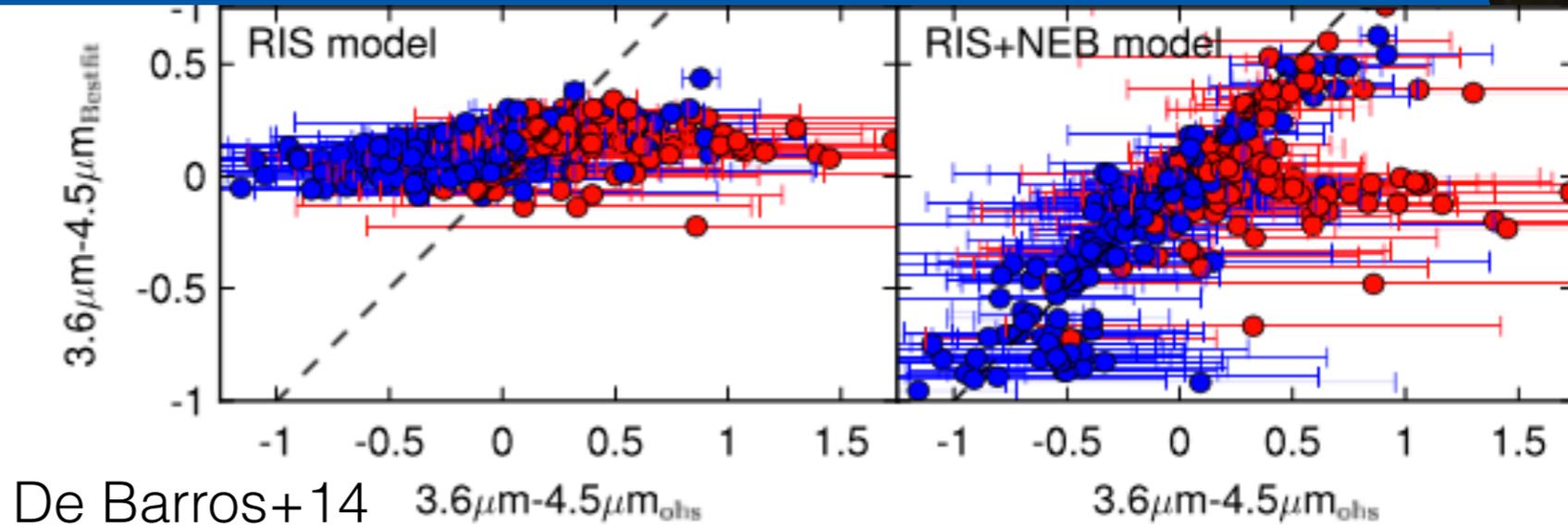
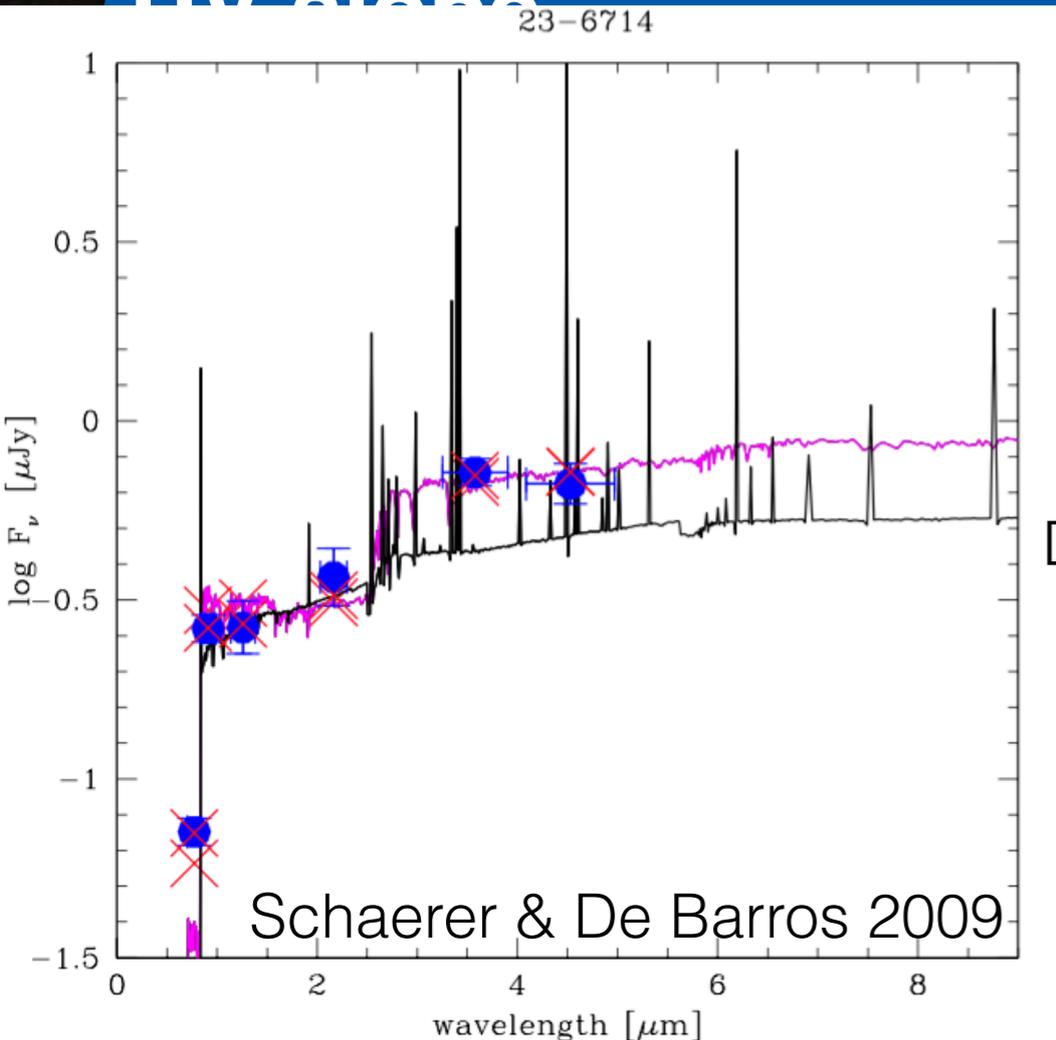
assumptions (SFH, dust attenuation
C1 and 2 channels affected by
Marmol-Queralto, Capak, Labbe,

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Exploring a parameter space as large as possible (see C. Pacifici talk)

Galaxy physical properties at the edge of the cosmic reionization



assumptions (SFR, dust attenuation)
C1 and 2 channels affected by
Marmol-Queralto, Capak, Labbe,

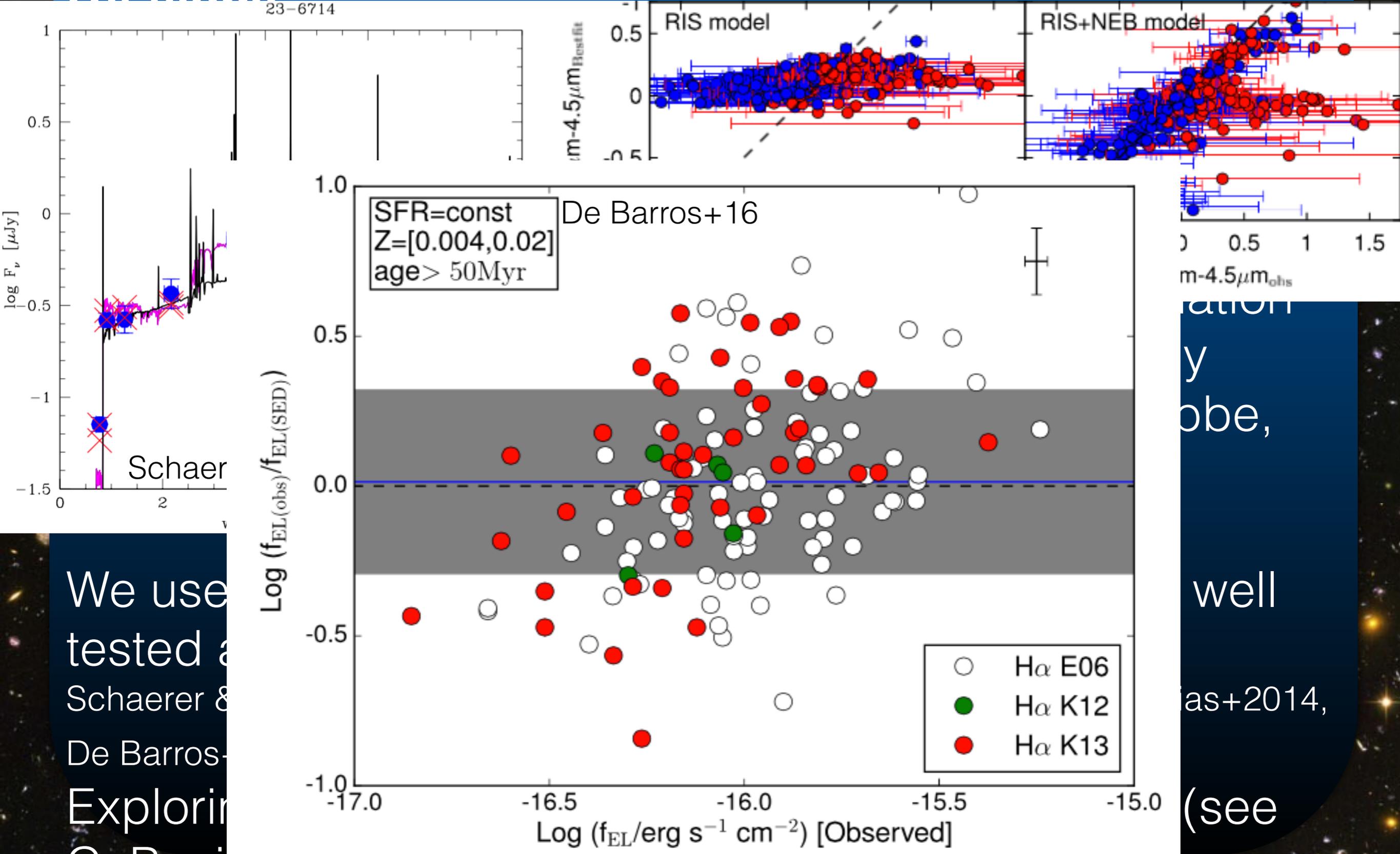
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Galaxy physical properties at the edge of the cosmic reionization

UV slope

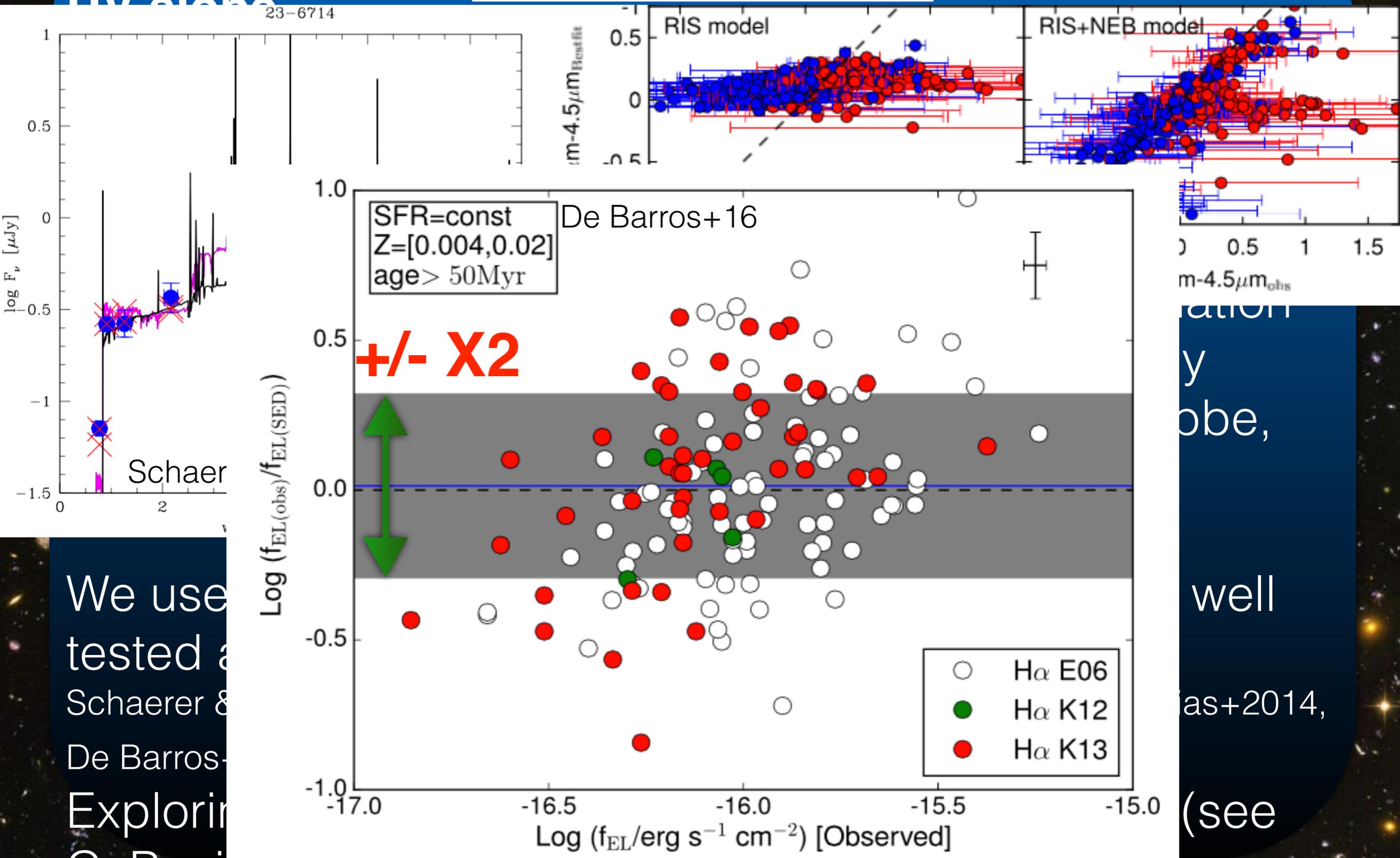


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C. Pacific talk)

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Galaxy physical properties at the edge of the cosmic reionization

UV slope

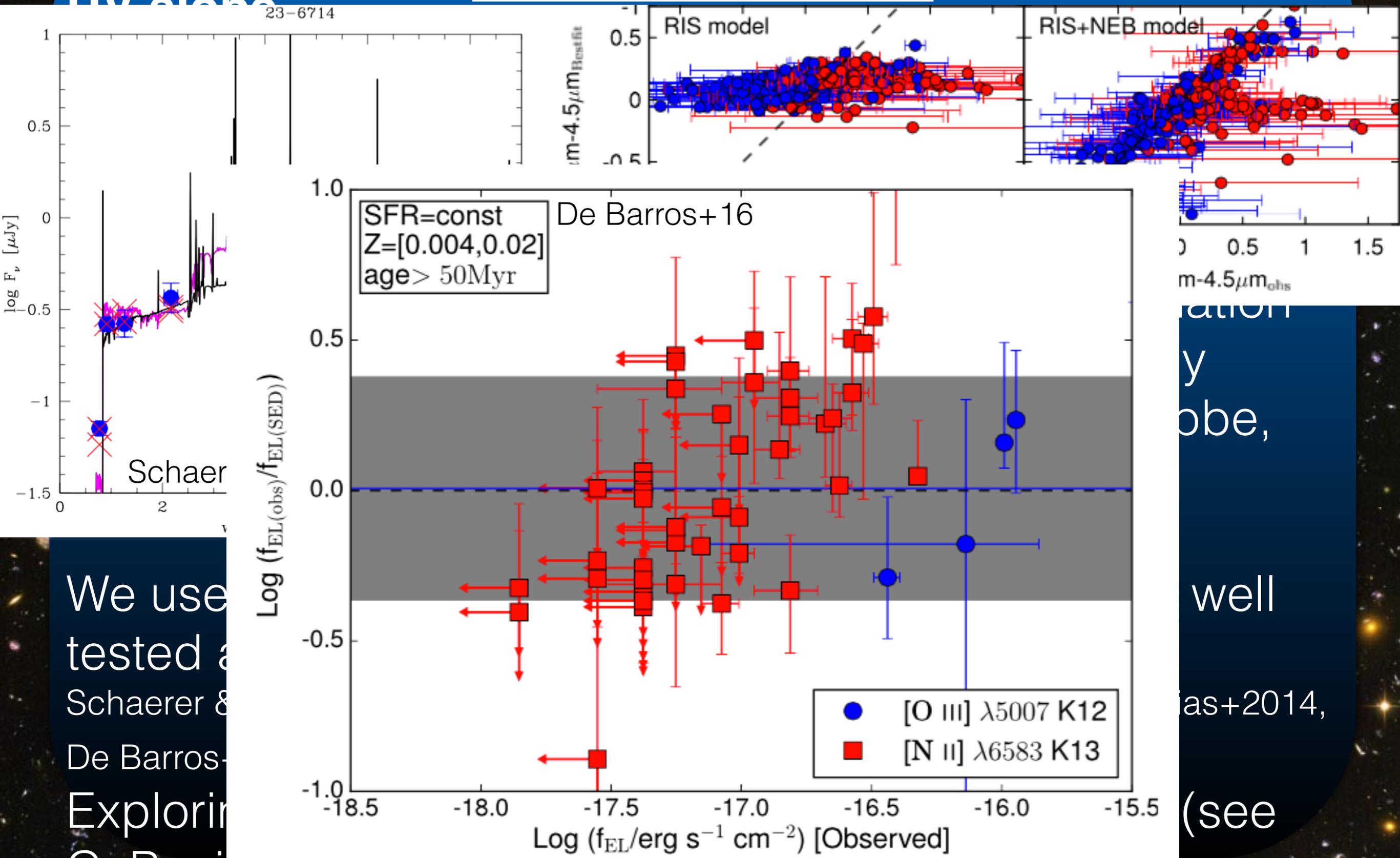


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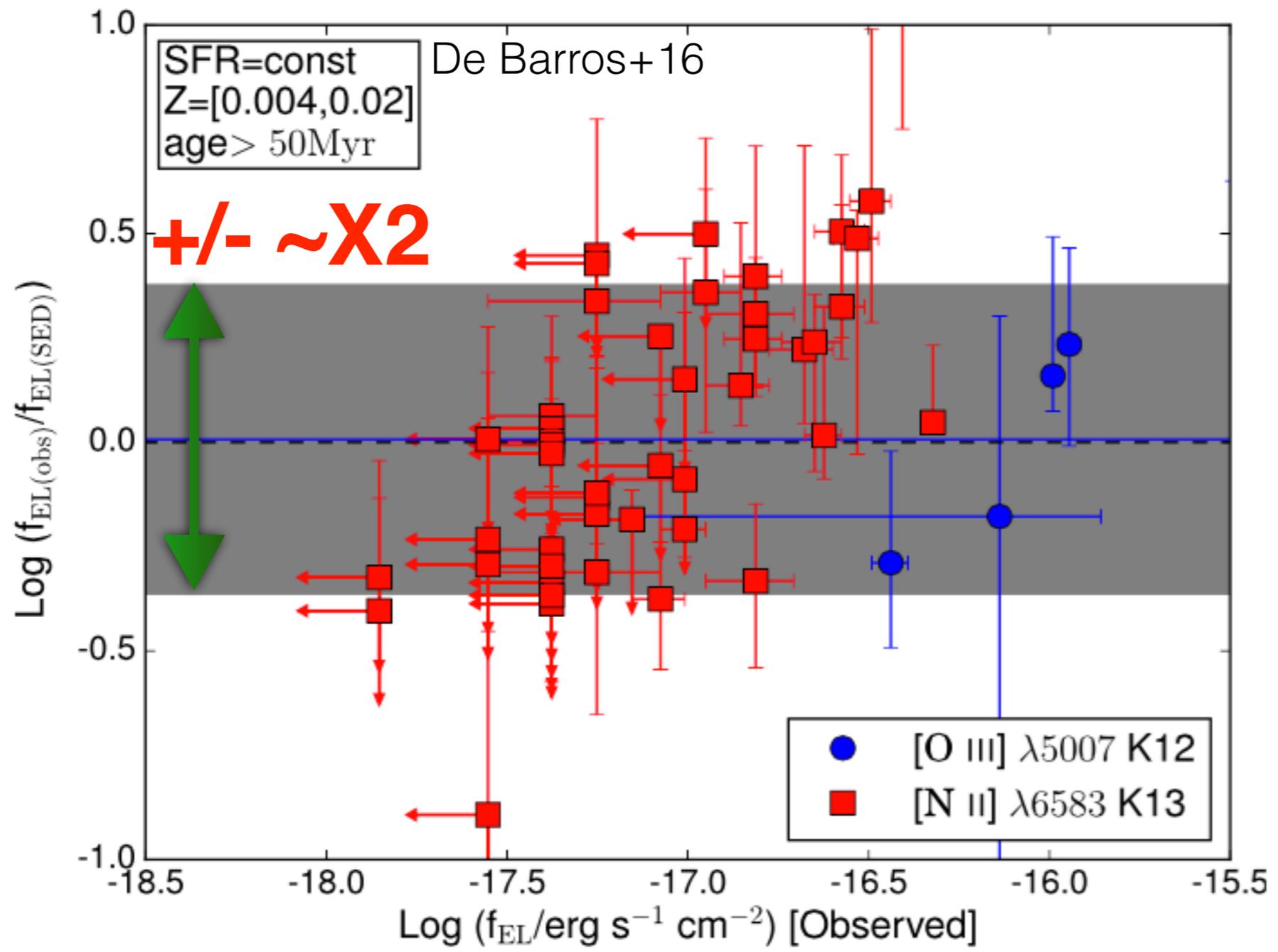
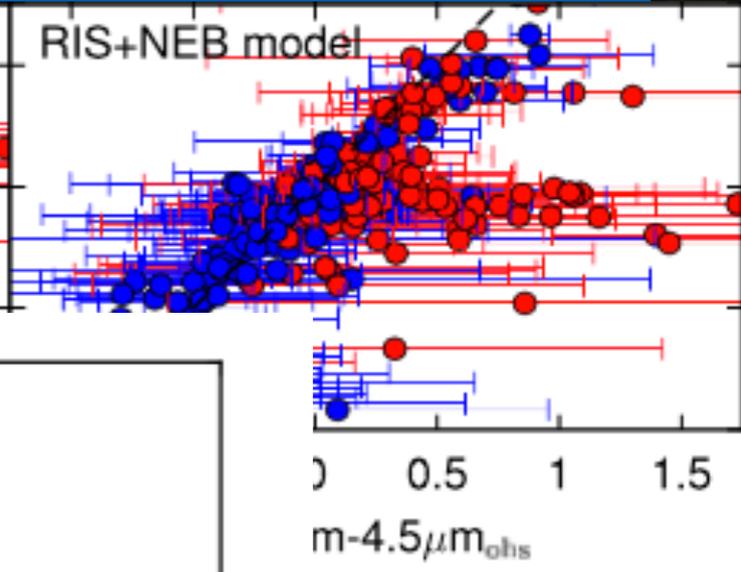
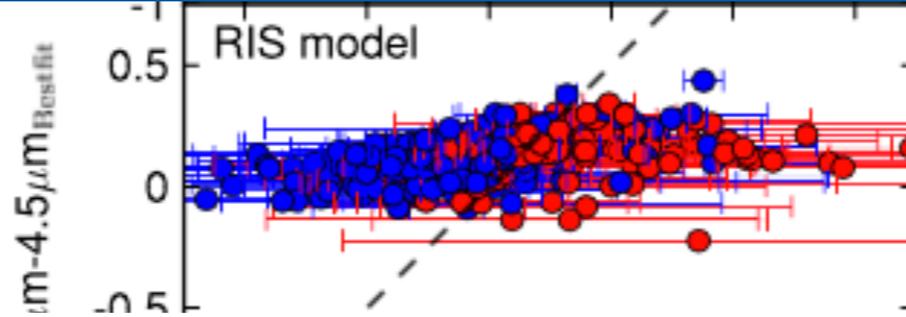
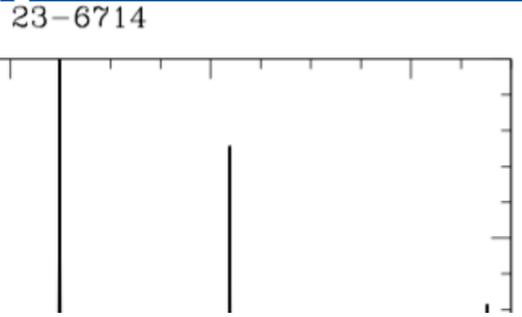
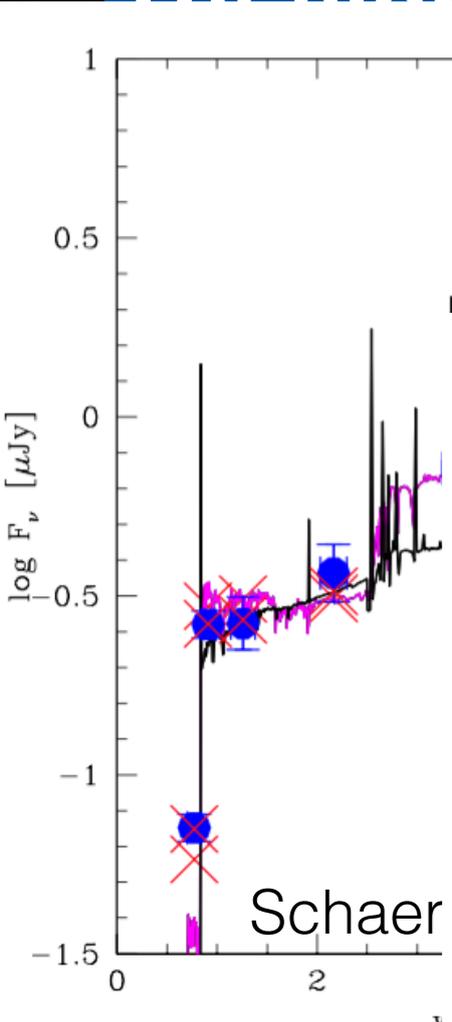


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Ion2: a plausible high-redshift Lyman
continuum emitter

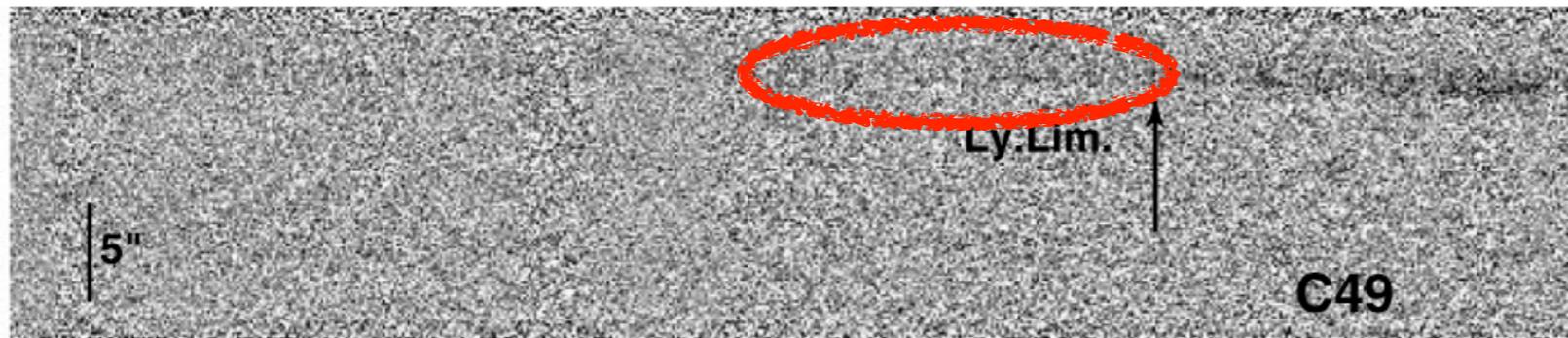
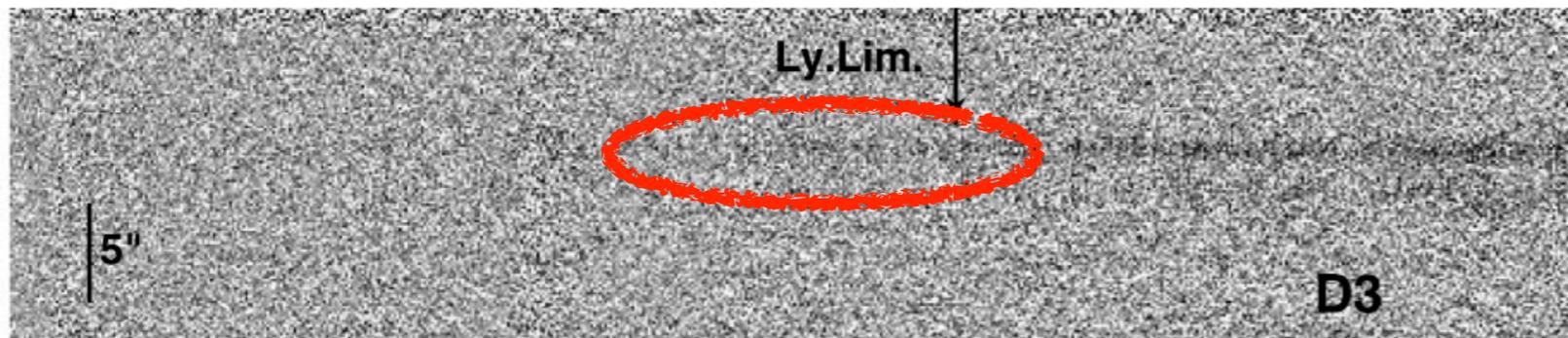
Status until (very) recently

SIII 1260

OI+SIII CII 1334 ?
1303

Ion2: a plausible high-redshift Lyman continuum emitter

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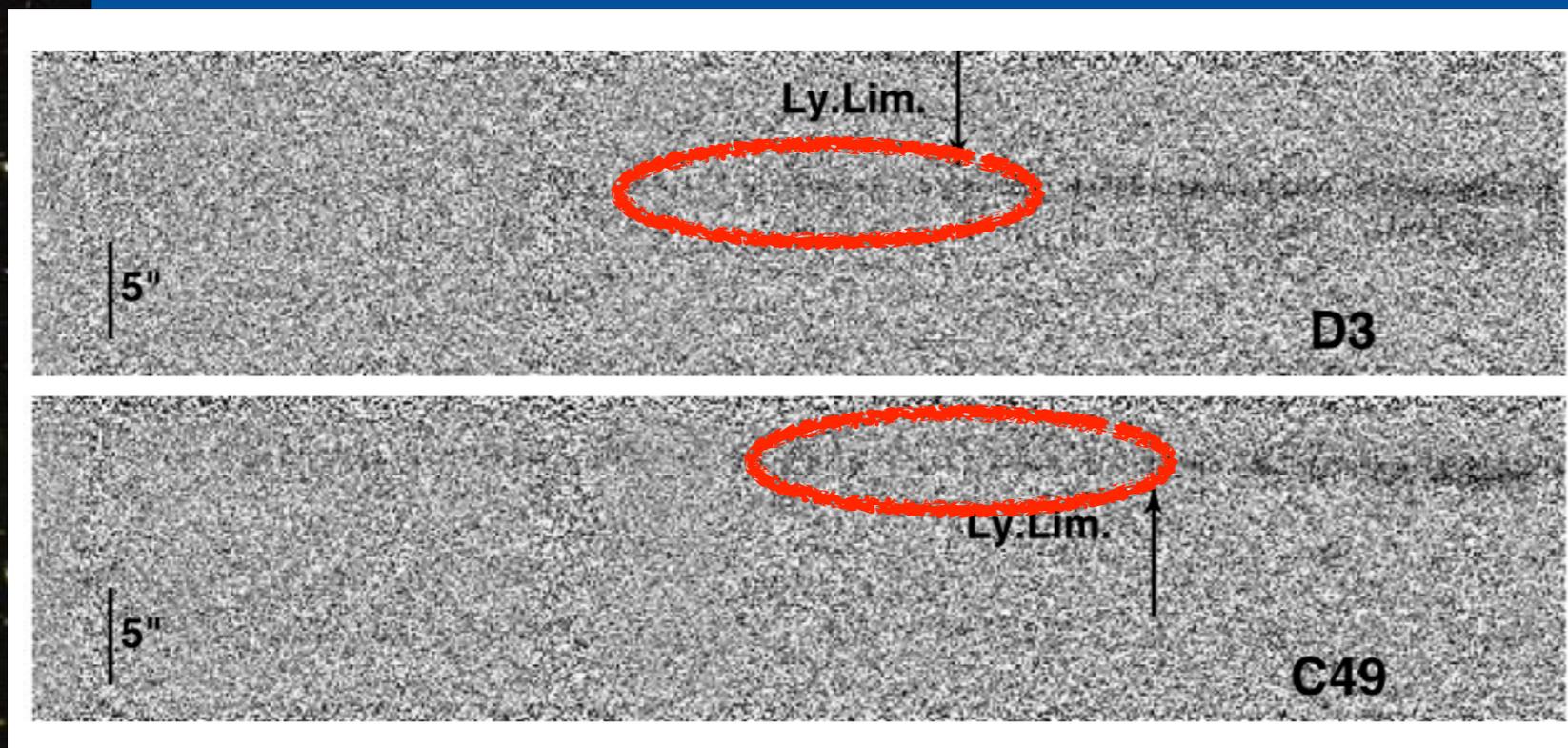
Shapley+2006

SIII 1260

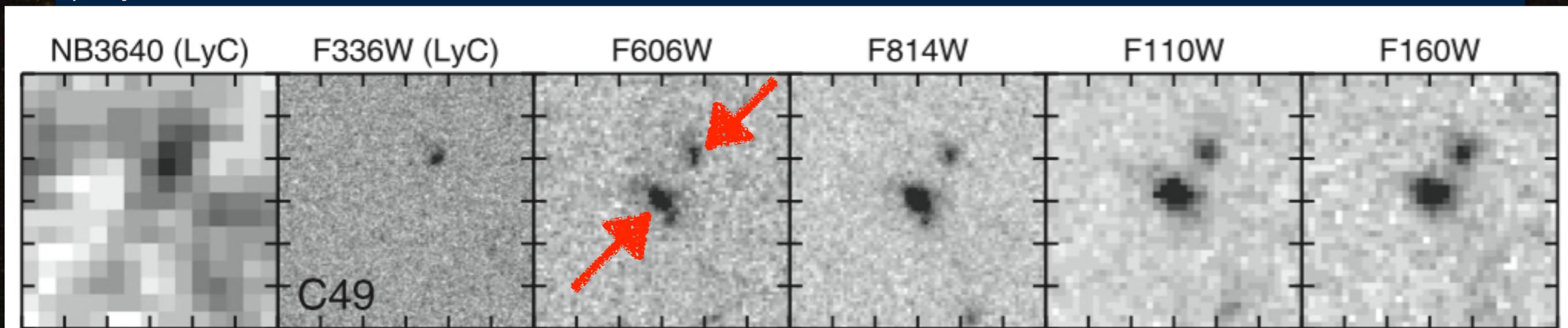
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Ion2: a plausible high-redshift Lyman continuum emitter

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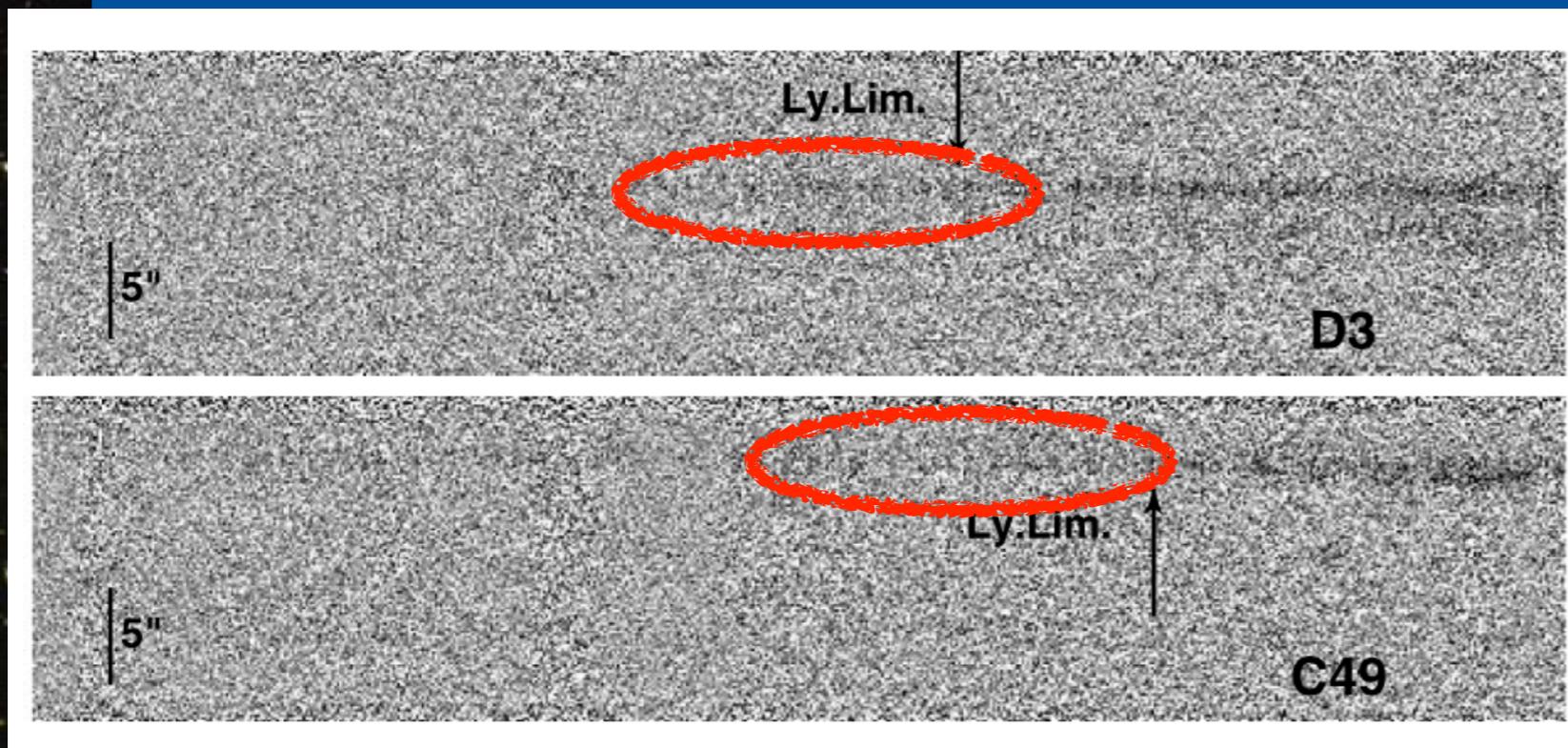
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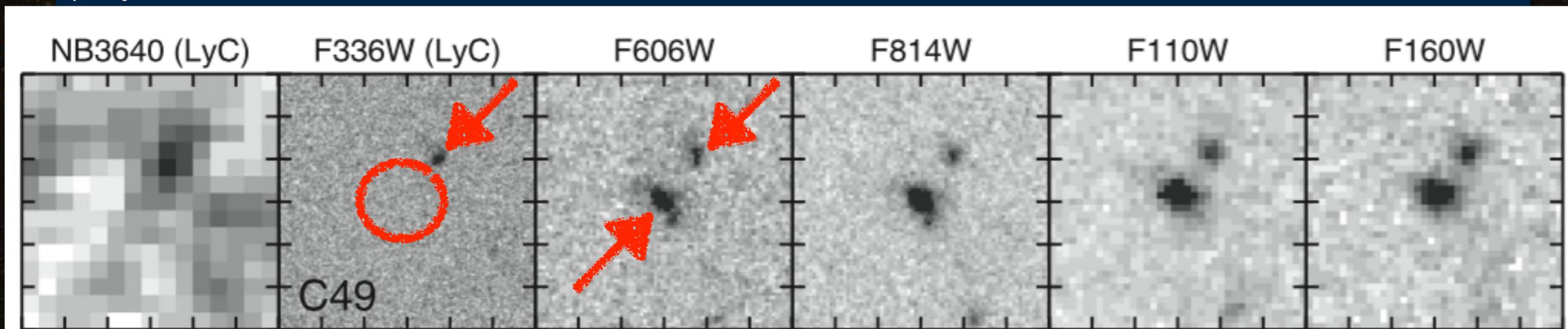
Siana+15

Ion2: a plausible high-redshift Lyman continuum emitter

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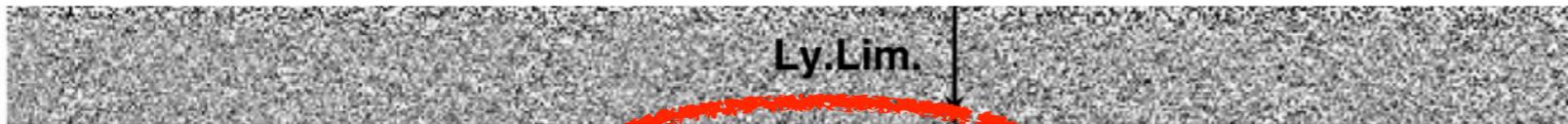
Shapley+2006



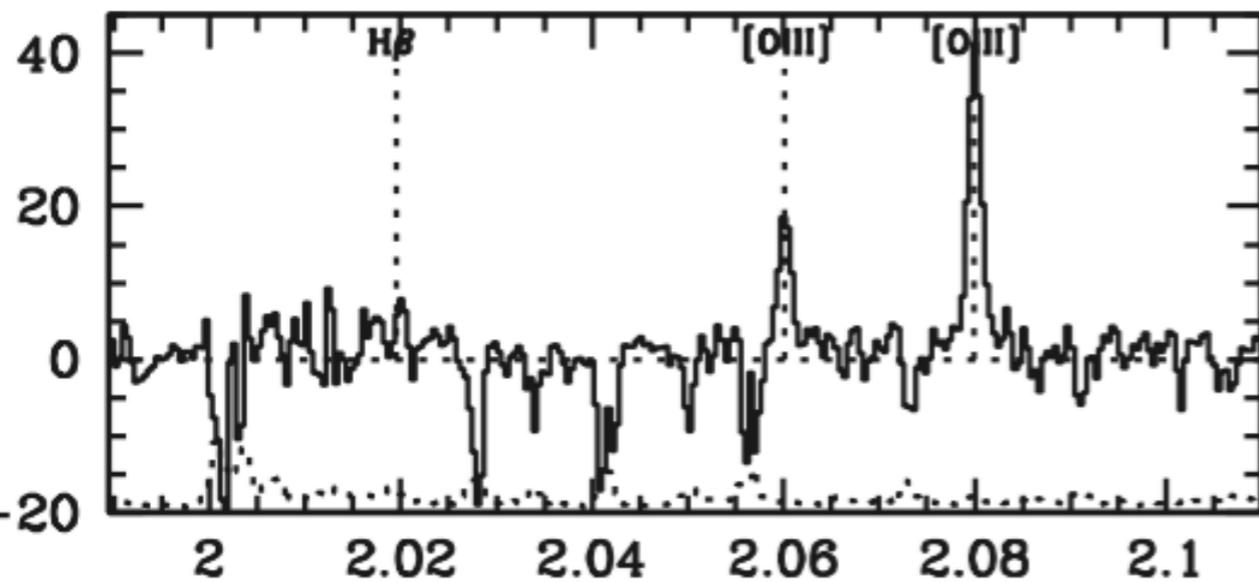
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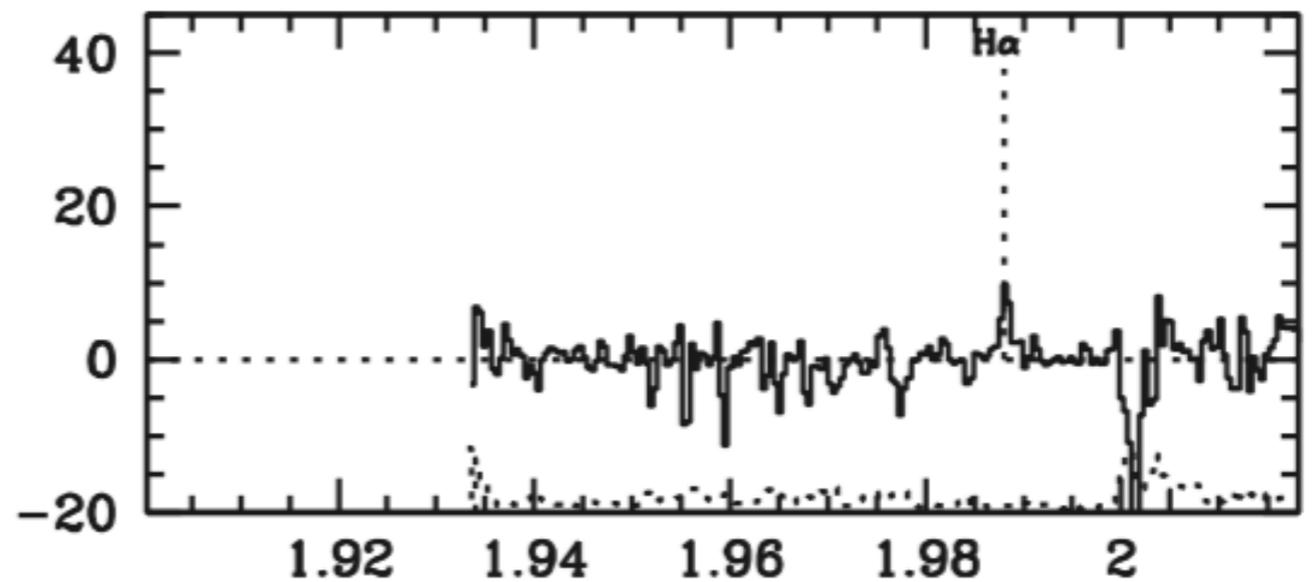
Status until (very) recently



C49 $z=3.1532$



C49_NW $z=2.0286$



NB3640 (LyC)

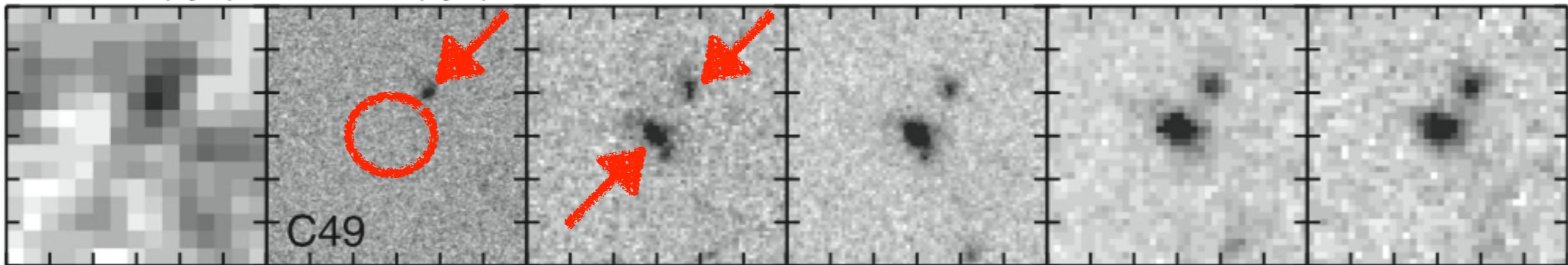
F336W (LyC)

F606W

F814W

F110W

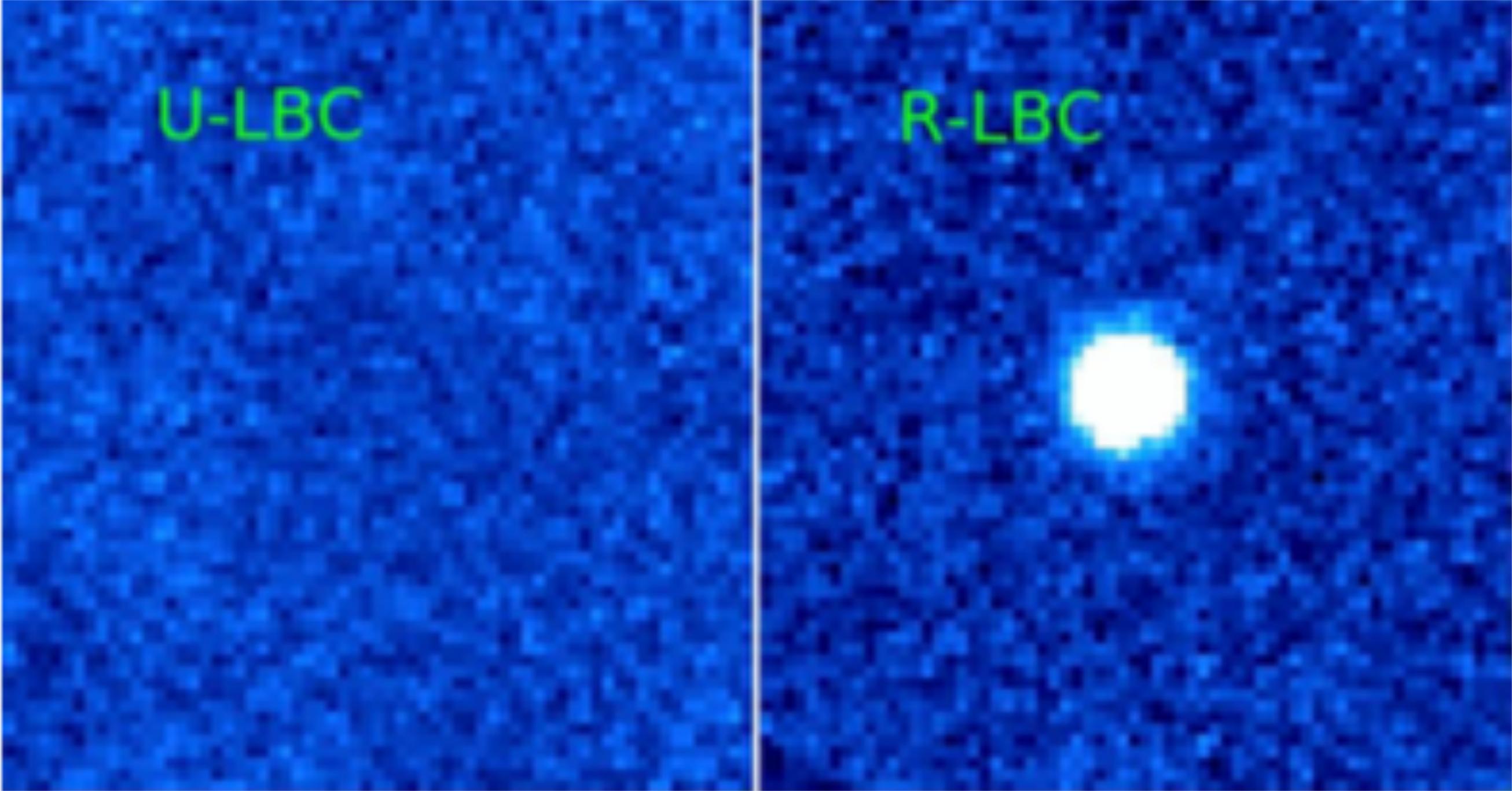
F160W



Ion2: a plausible high-redshift Lyman
continuum emitter

Status until (very) recently

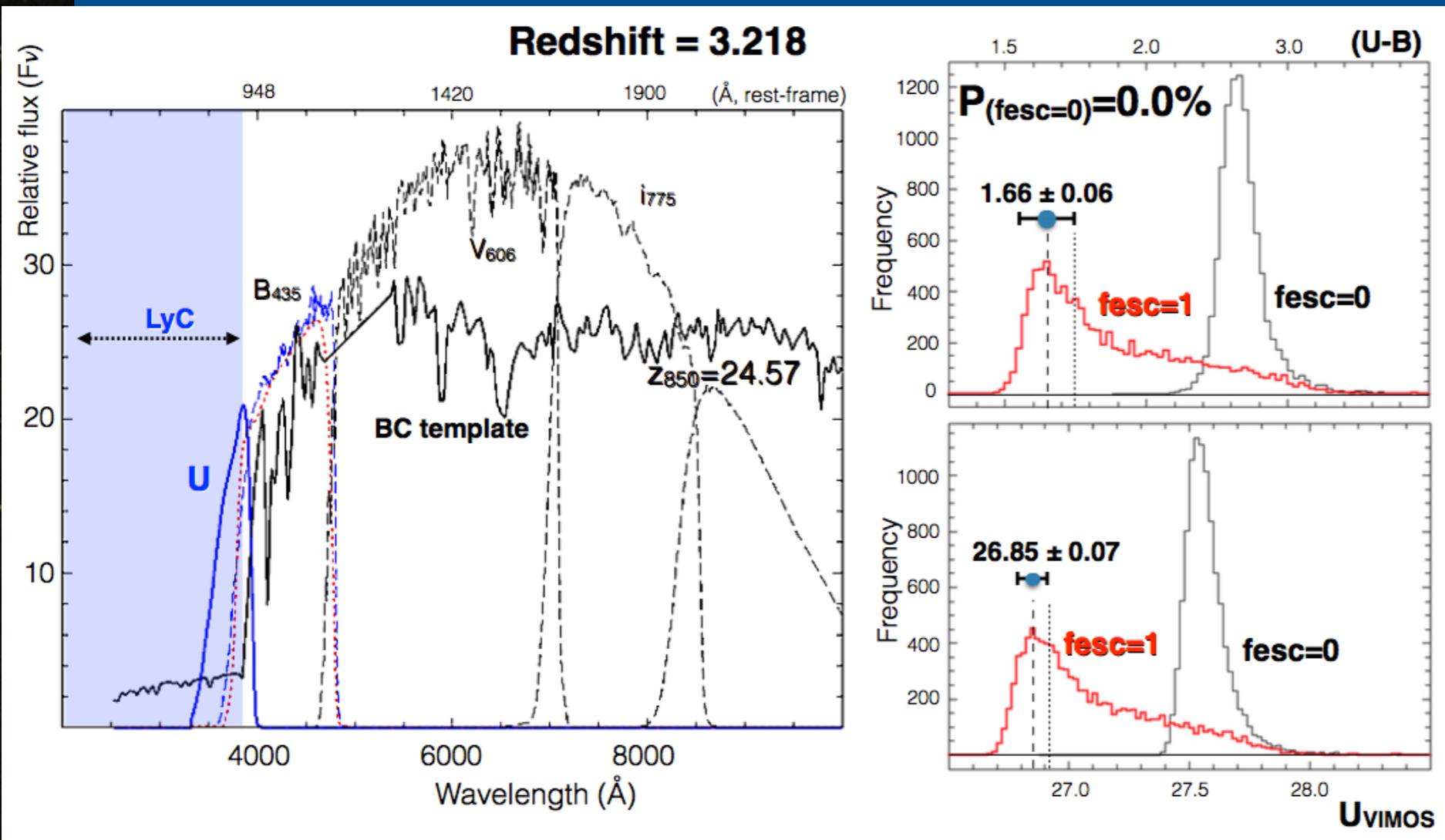
U-LBC



R-LBC

Ion2: a plausible high-redshift Lyman continuum emitter

Selection, indirect evidence, direct evidence:



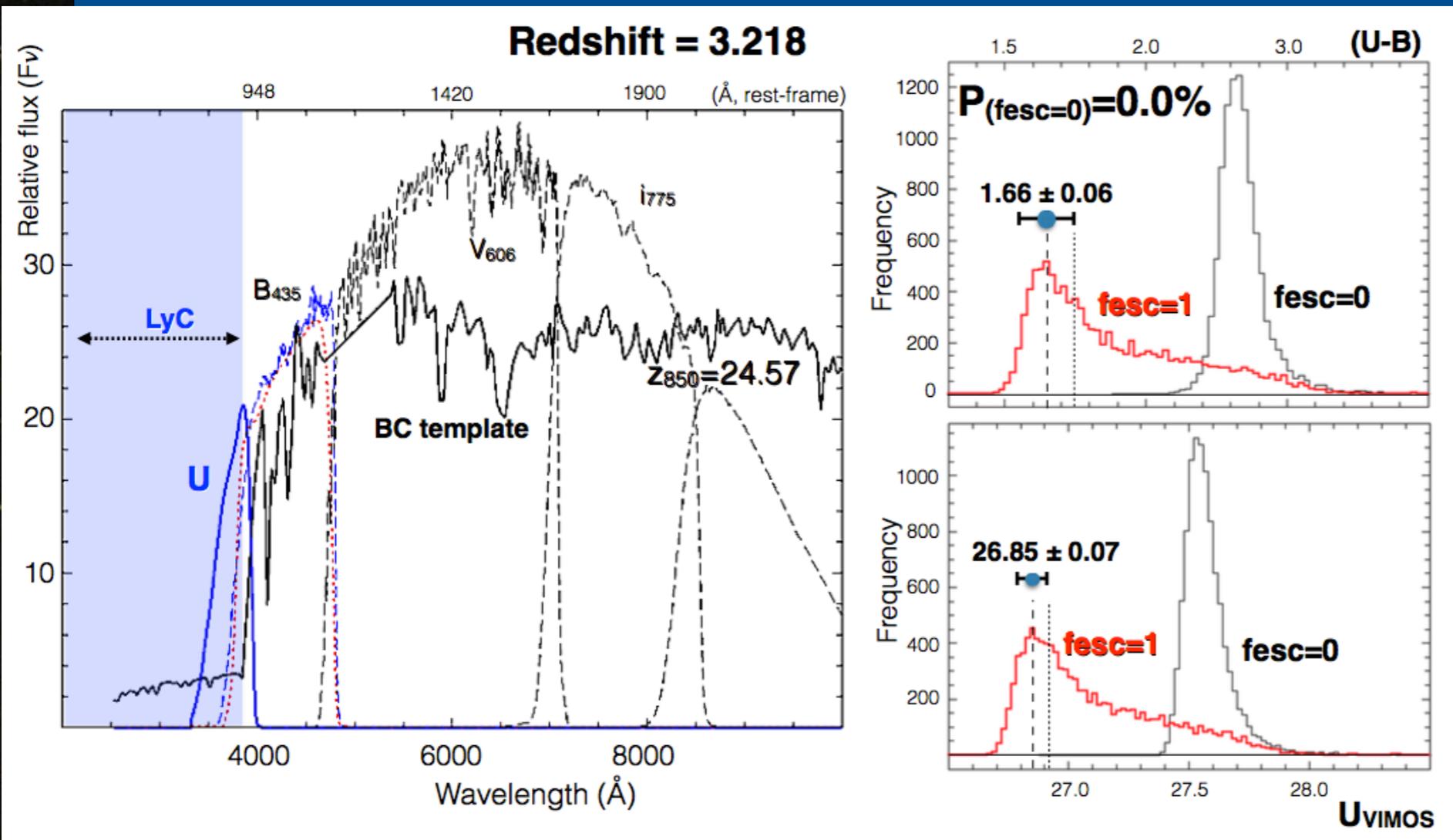
Vanzella+15

SIII 1260

OI+SIII 1303
CII 1334 ?

Ion2: a plausible high-redshift Lyman continuum emitter

Selection, indirect evidence, direct evidence:



- Use BC03 models with same UV slope

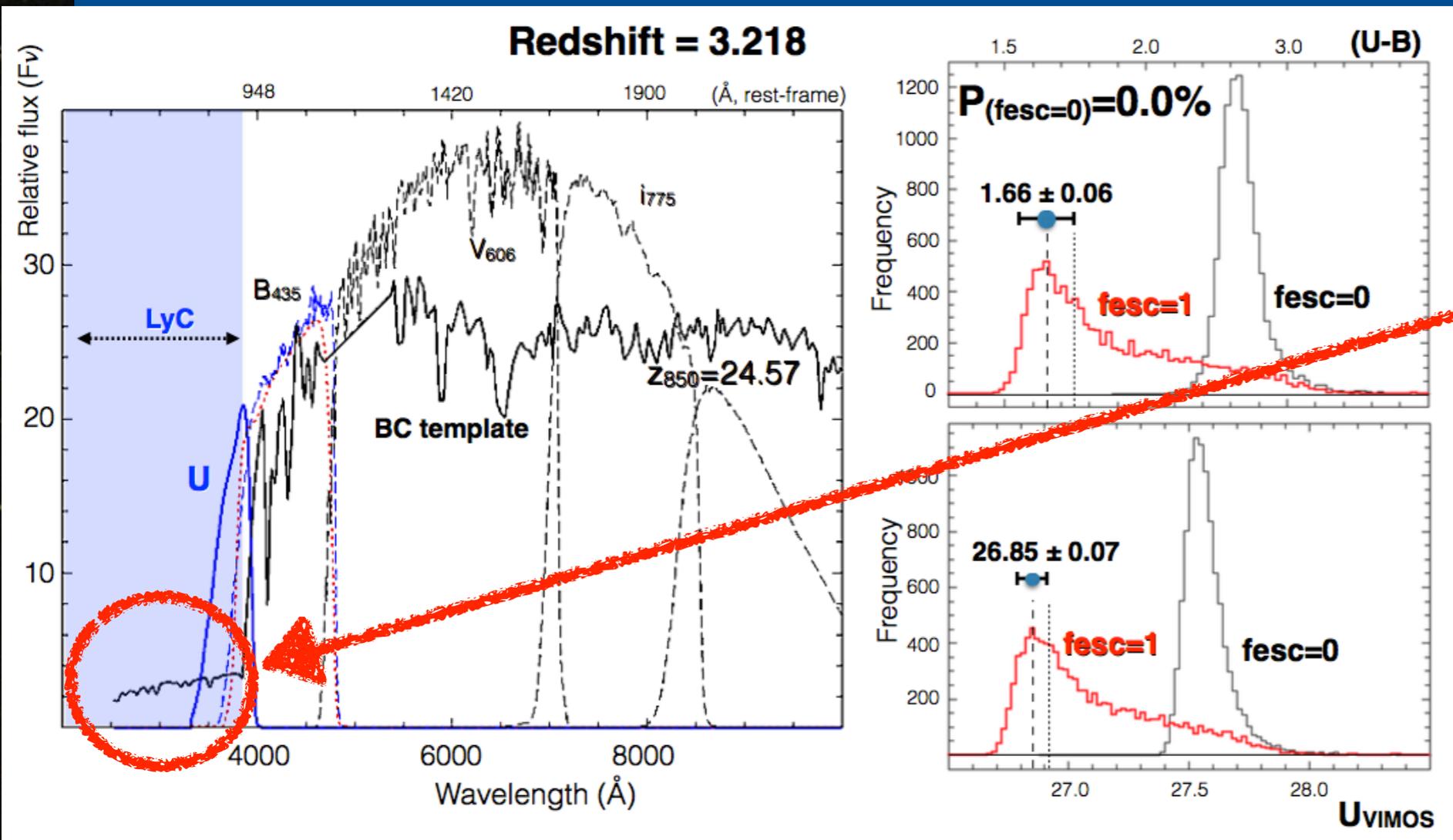
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Selection, indirect evidence, direct evidence:



- Use BC03 models with same UV slope
- Convolve templates with realistic IGM transmissions (Inoue 14)

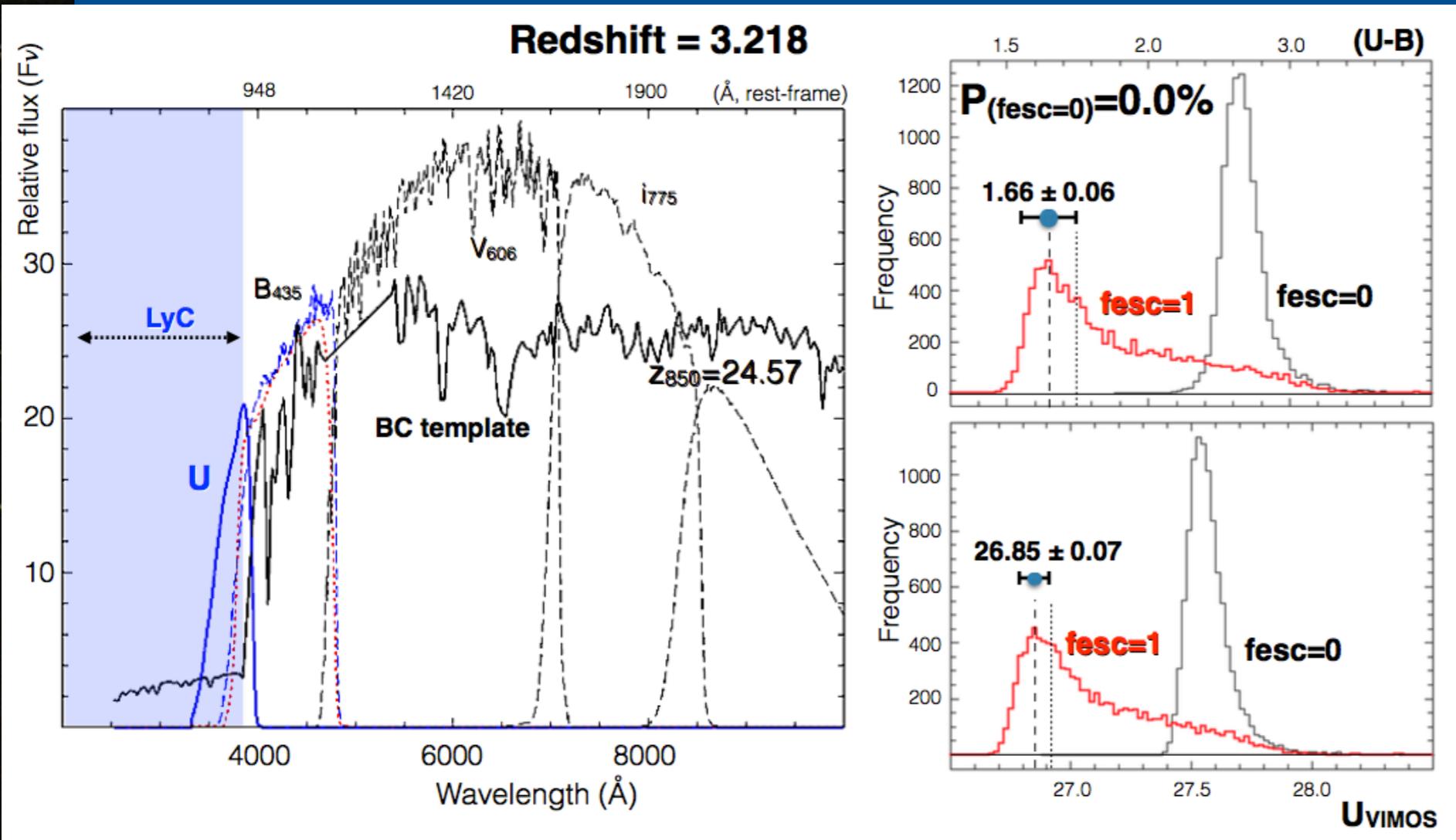
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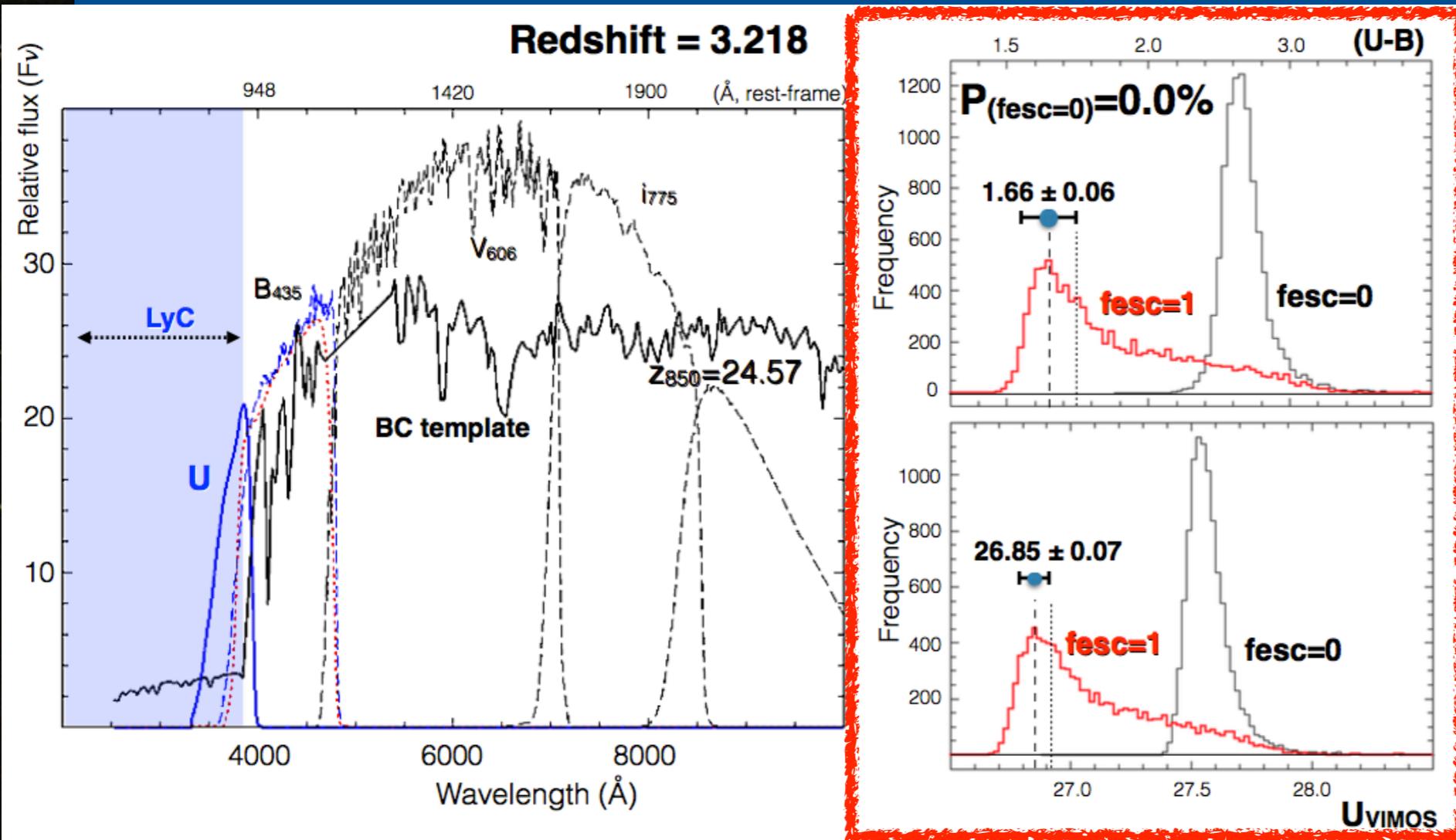
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Ion2: a plausible high-redshift Lyman continuum emitter

Selection, indirect evidence, direct evidence:



- Use BC03 models with same UV slope
- Convolve templates with realistic IGM transmissions (Inoue 14)
- Predict flux and colors turning on/off LyC escape fraction

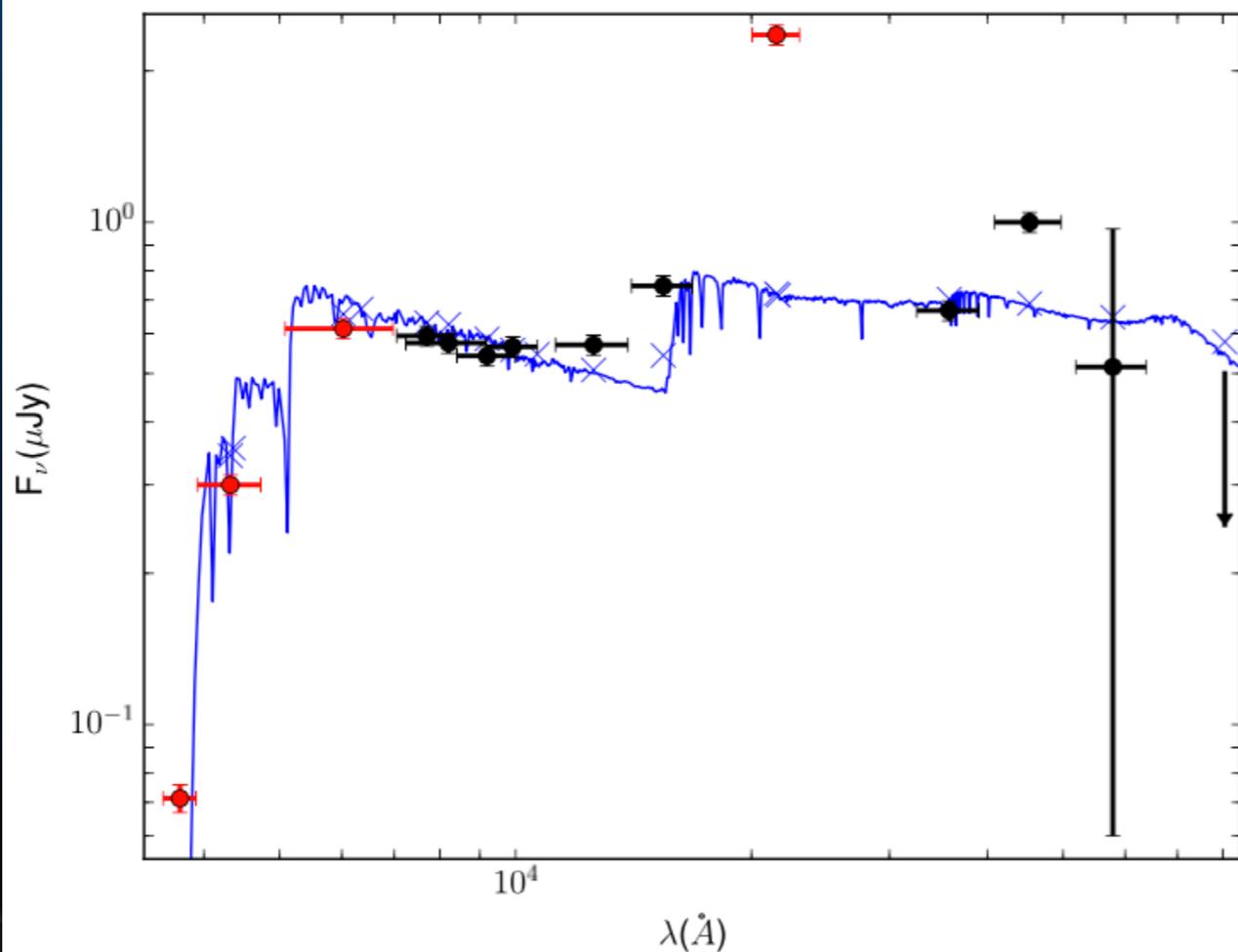
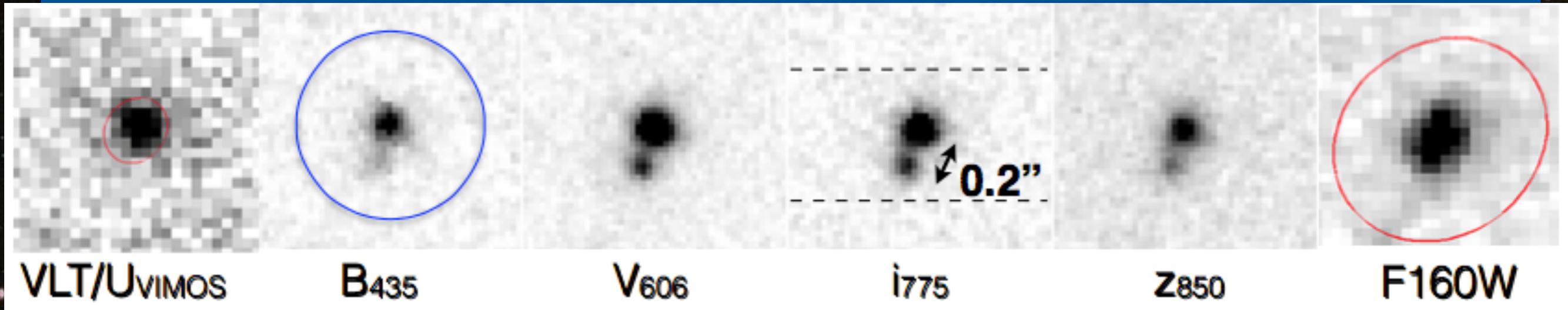
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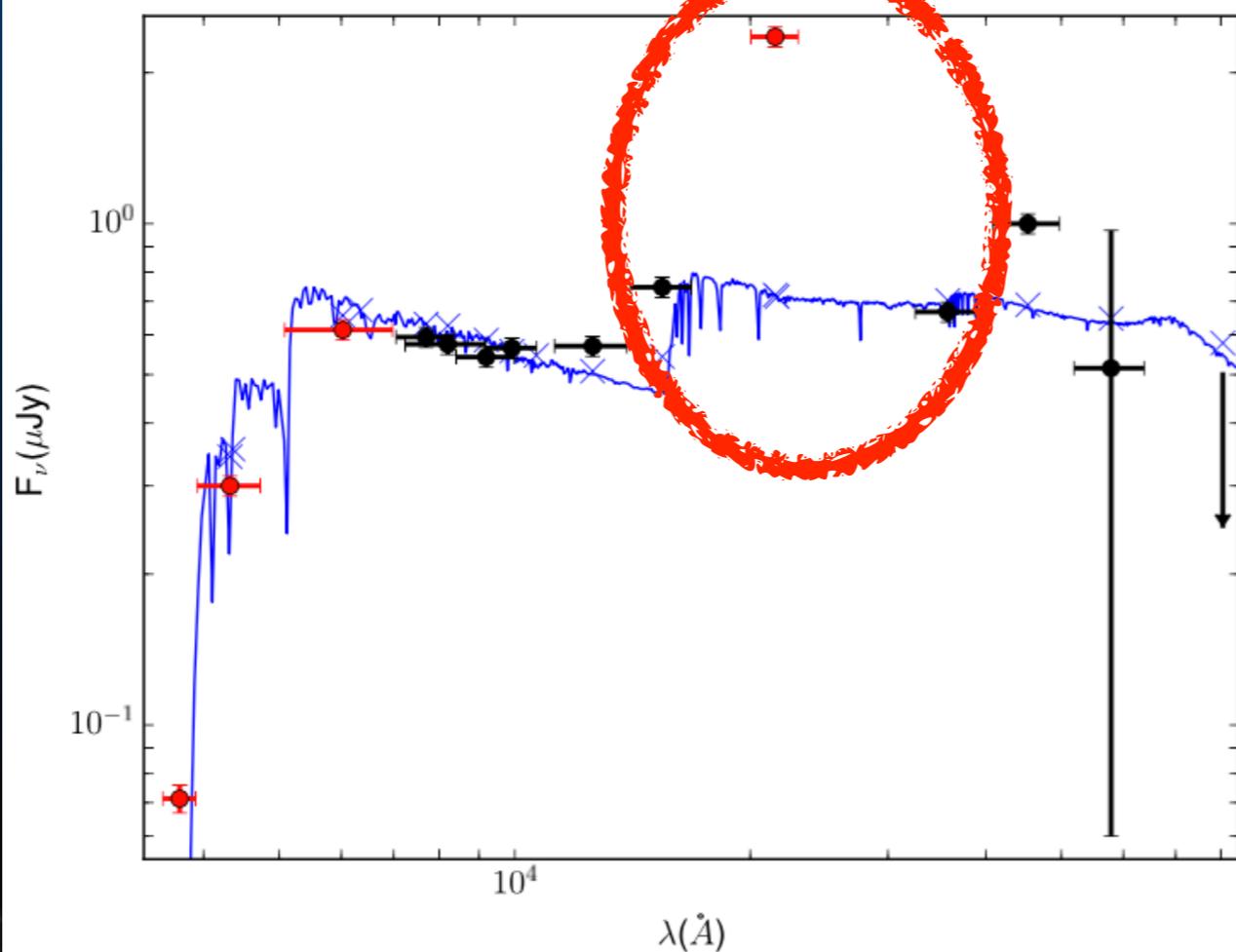
Large OIII+HB as at $z > 6$:
 Zitrin+15, Oesch+14,
 Smit+14

SIII 1260

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Ion2: a plausible high-redshift Lyman continuum emitter

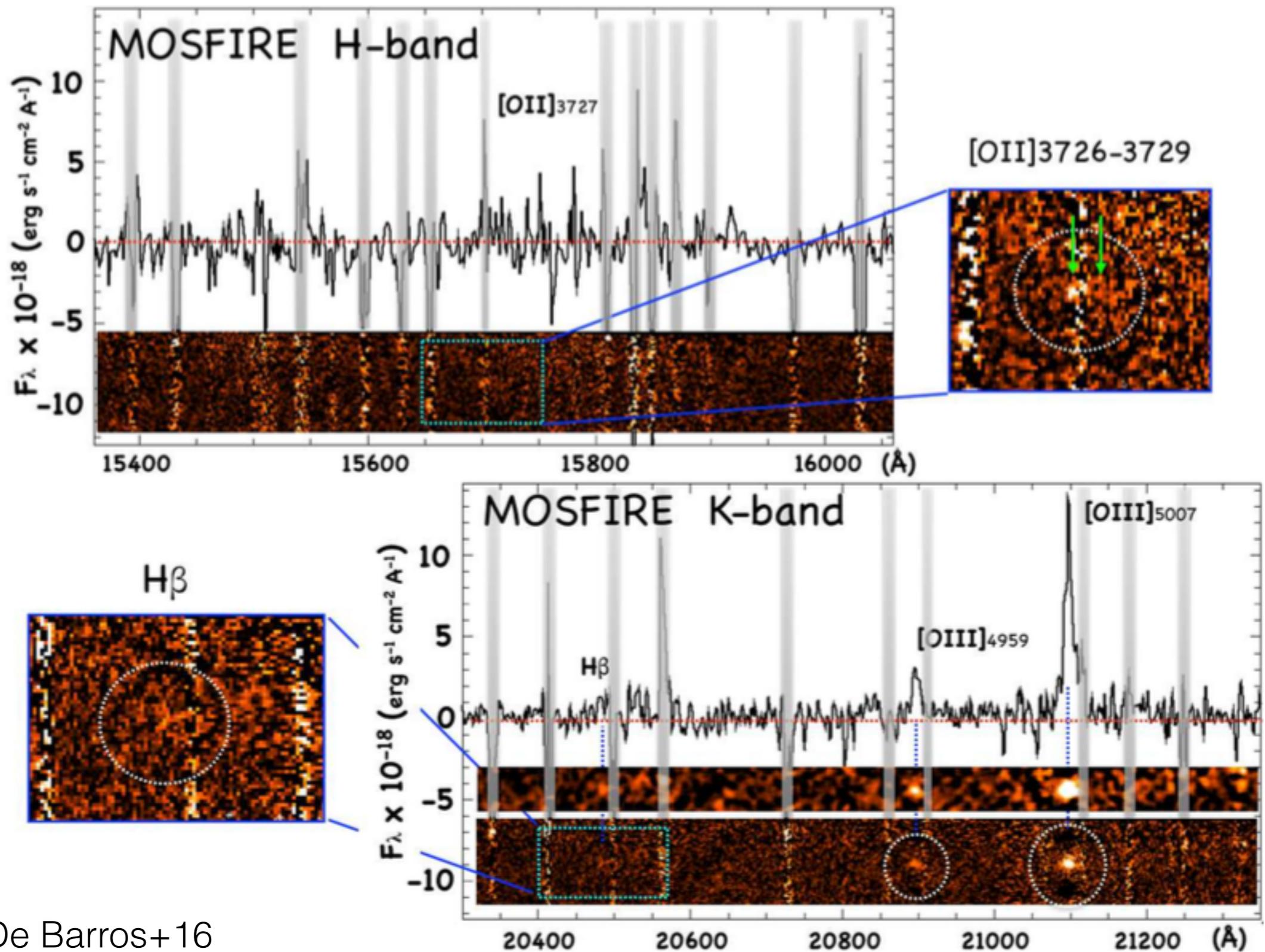
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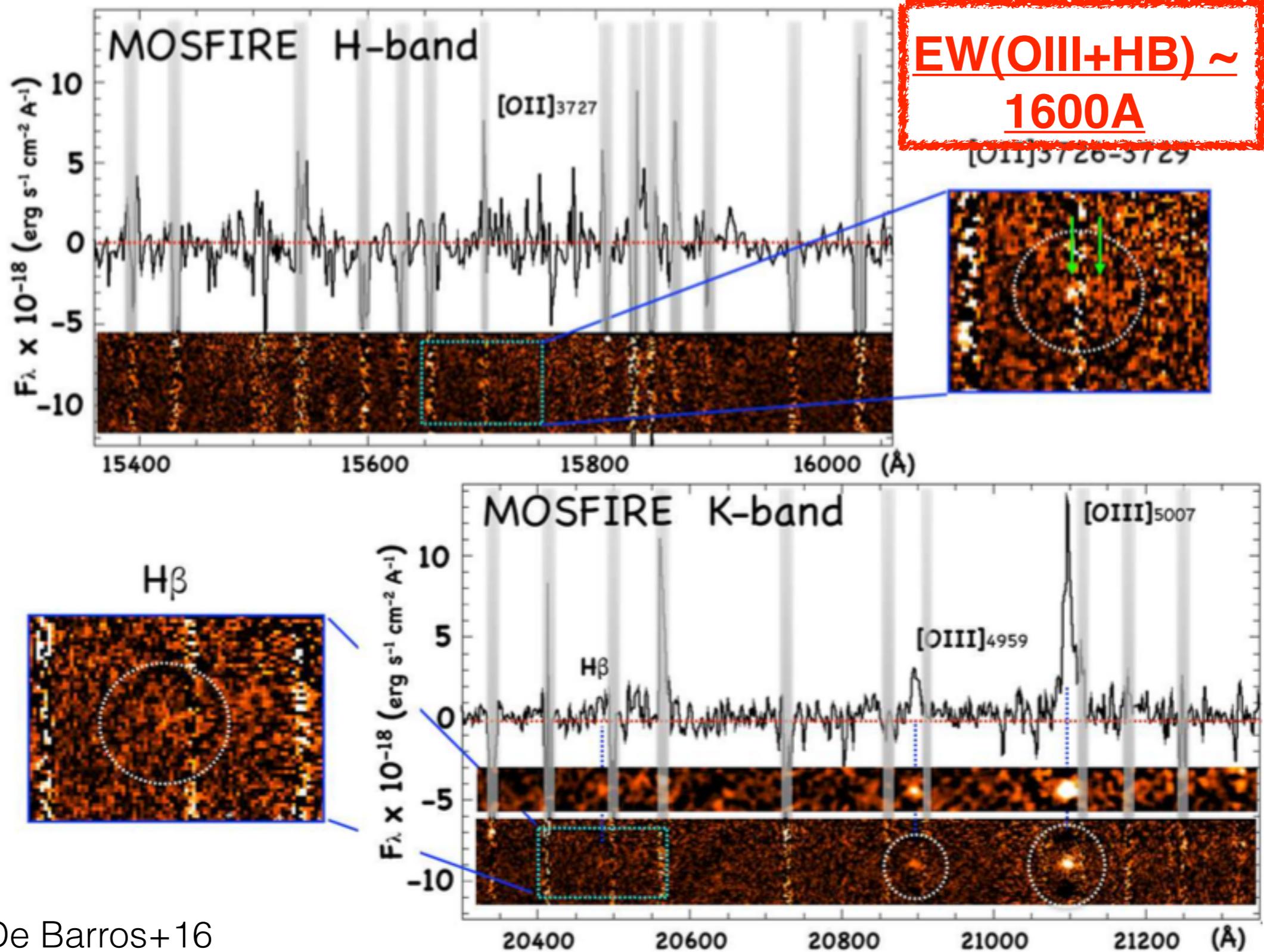
Ion2: a plausible high-redshift Lyman continuum emitter

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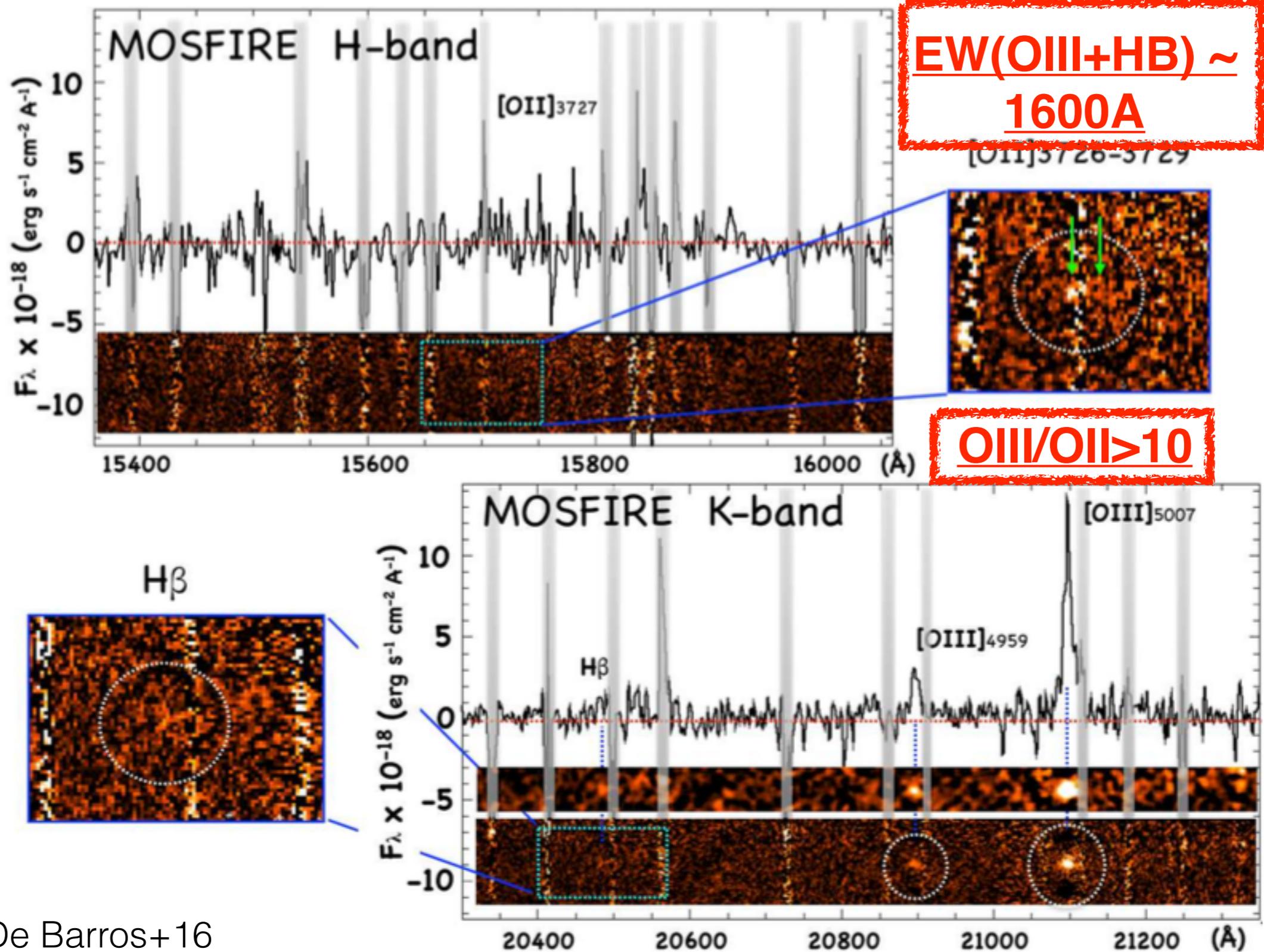
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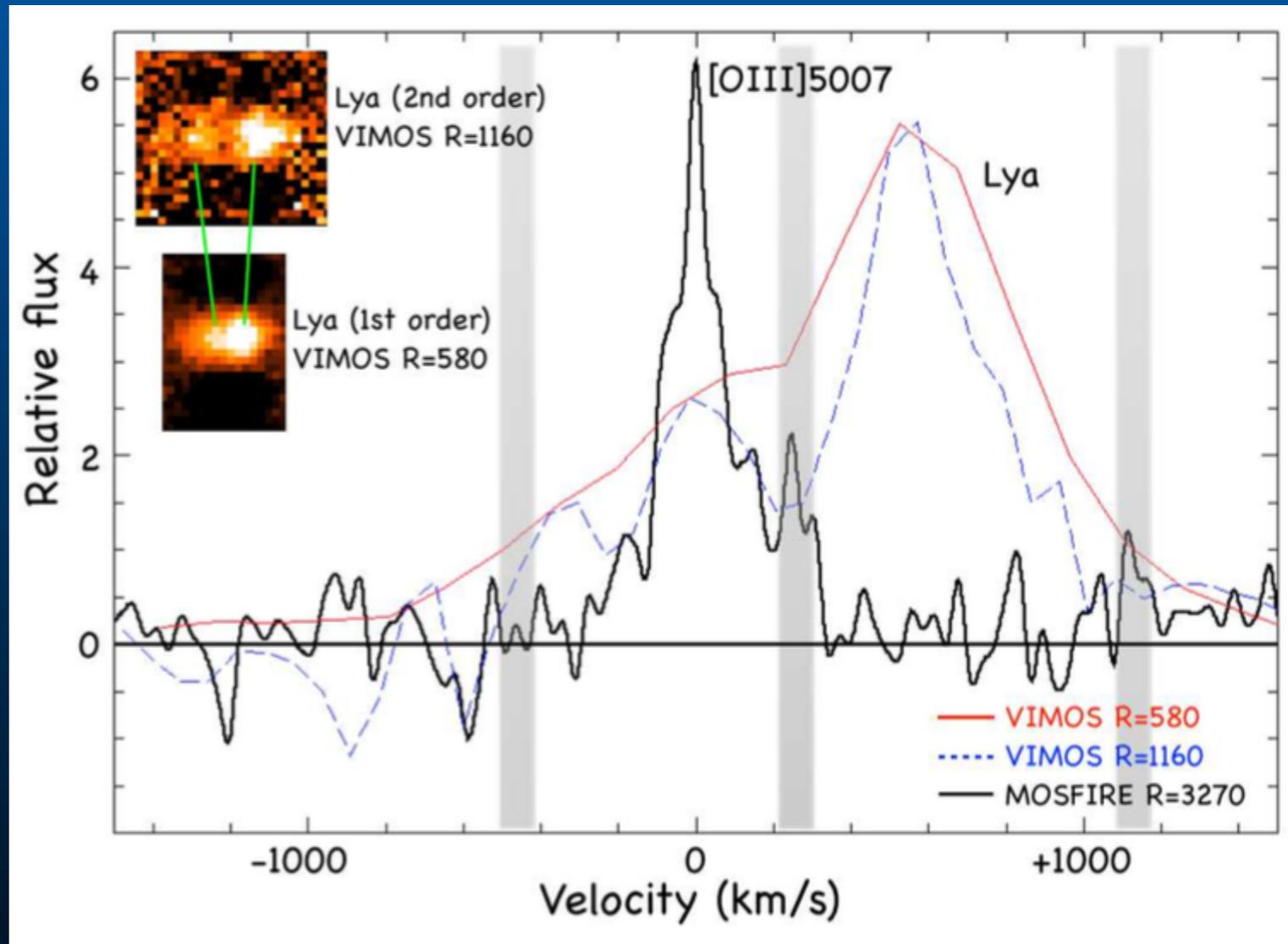
Ion2: a plausible high-redshift Lyman continuum emitter

Selection, indirect evidence, direct evidence:



Ion2: a plausible high-redshift Lyman continuum emitter

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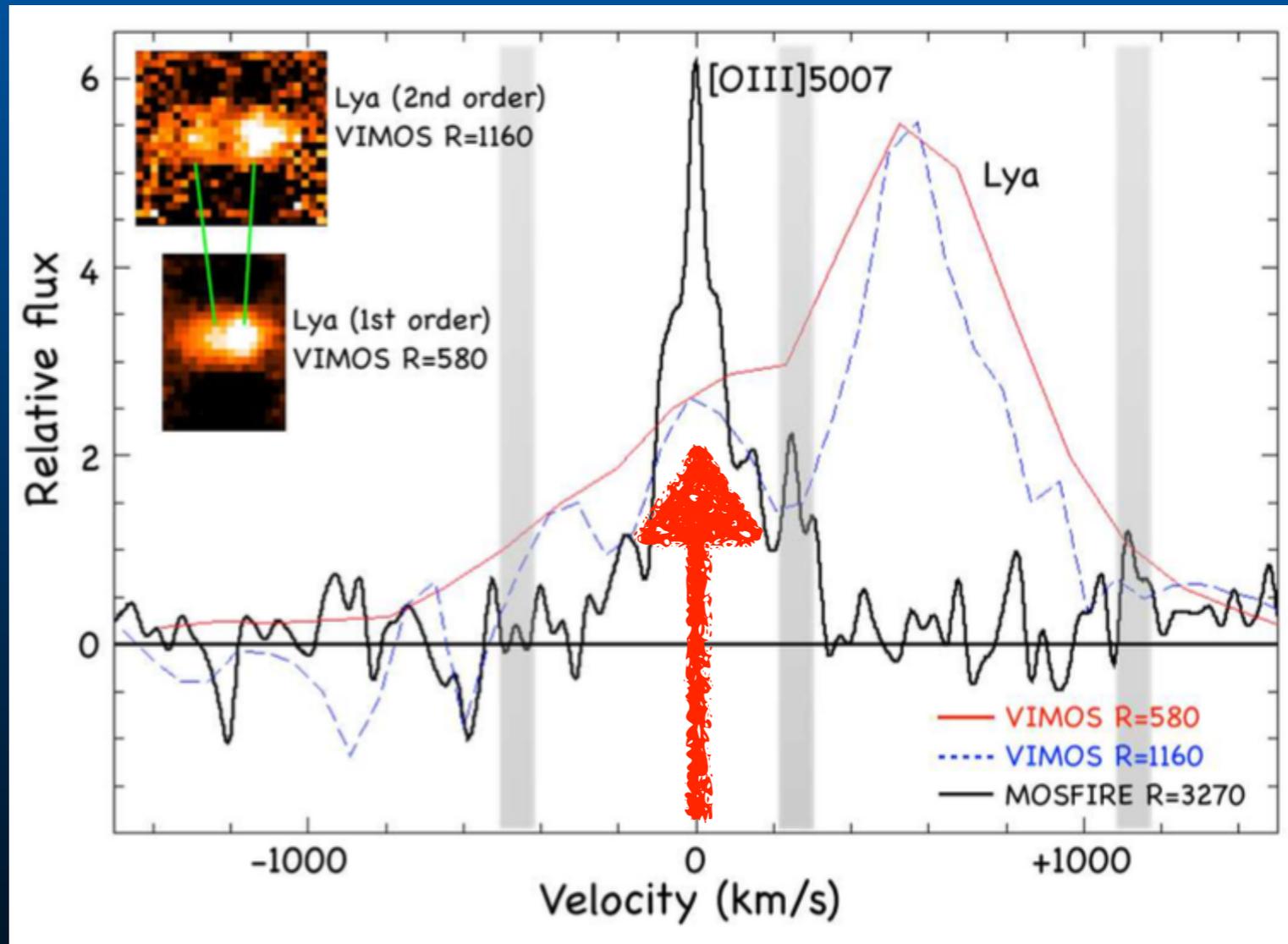


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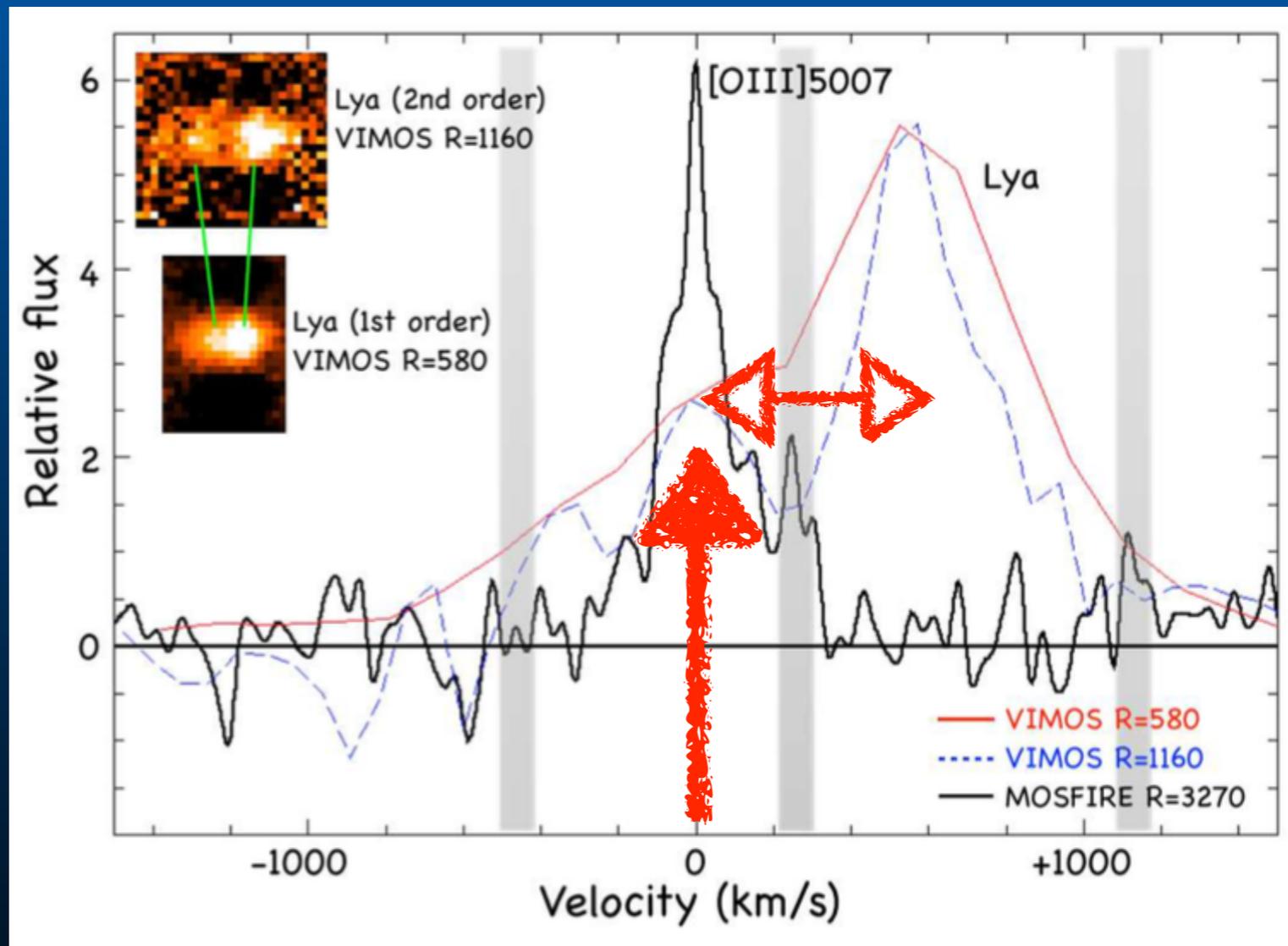


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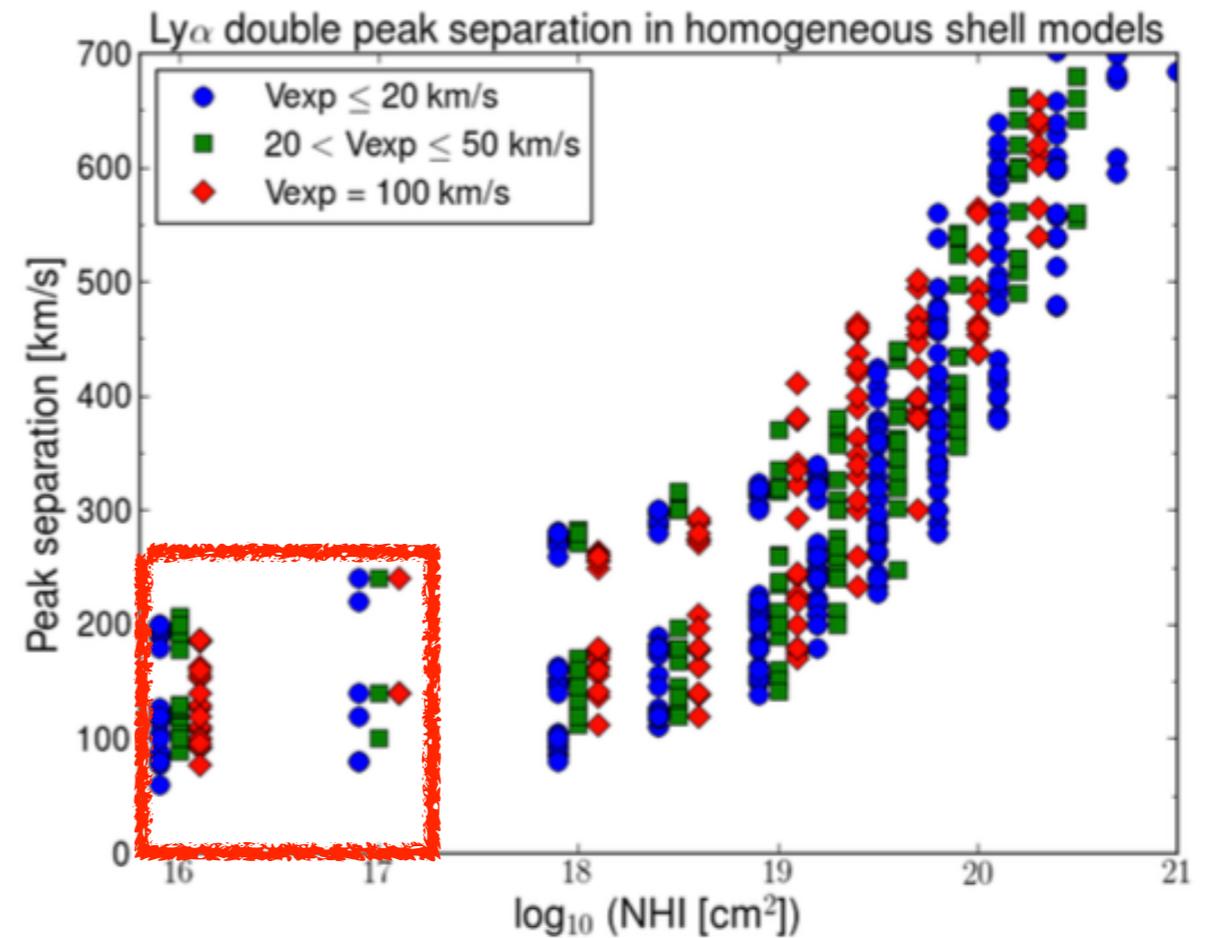
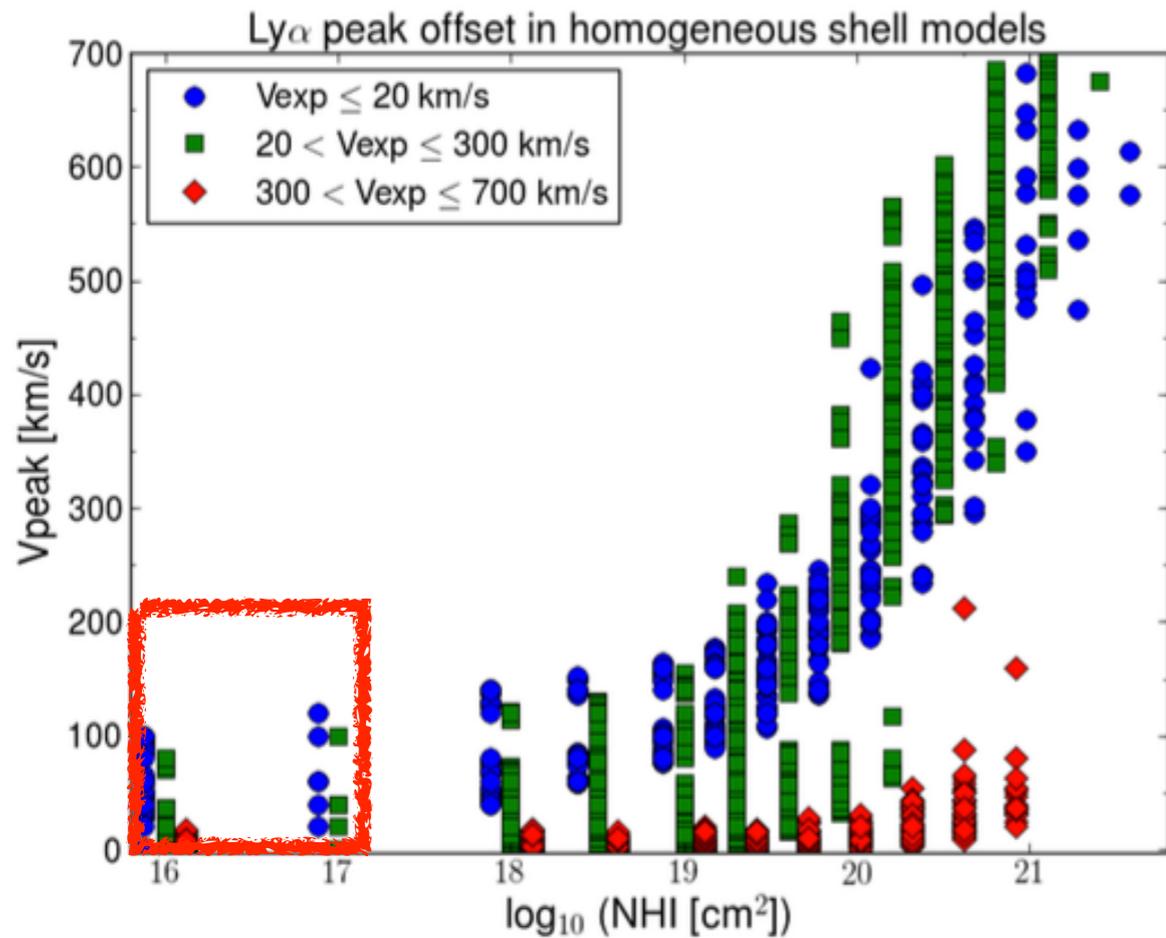


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Ion2: a plausible high-redshift Lyman continuum emitter

Selection, indirect evidence, direct evidence:



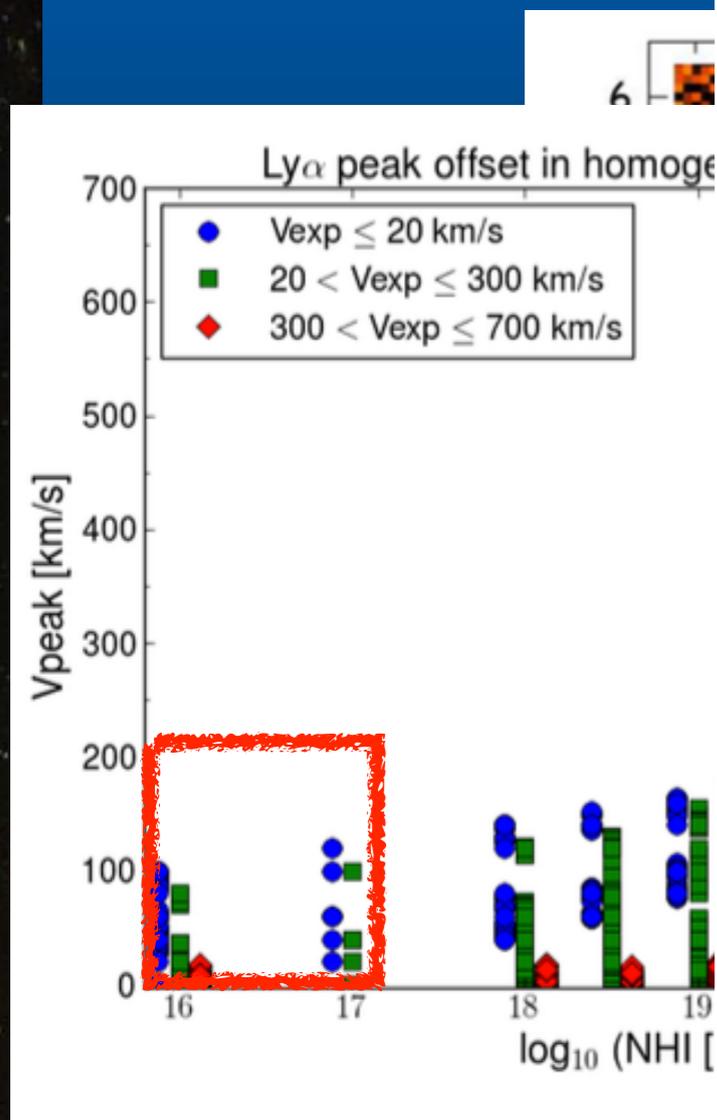
Verhamme+14

SIII 1260

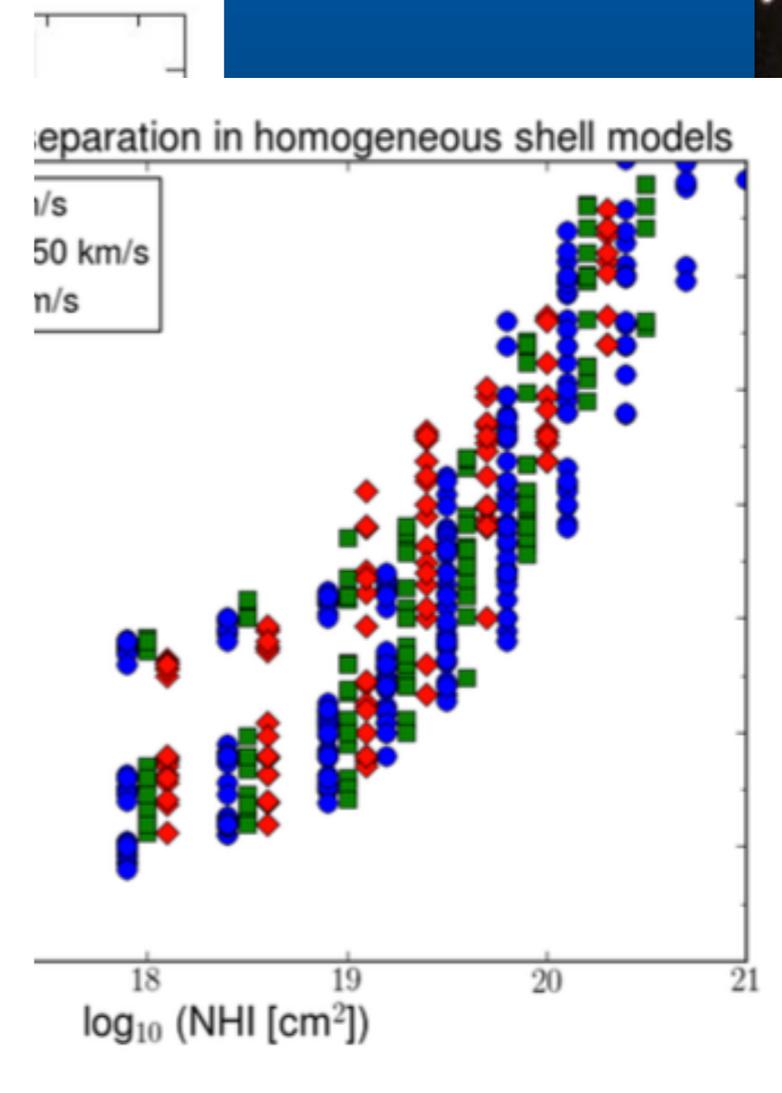
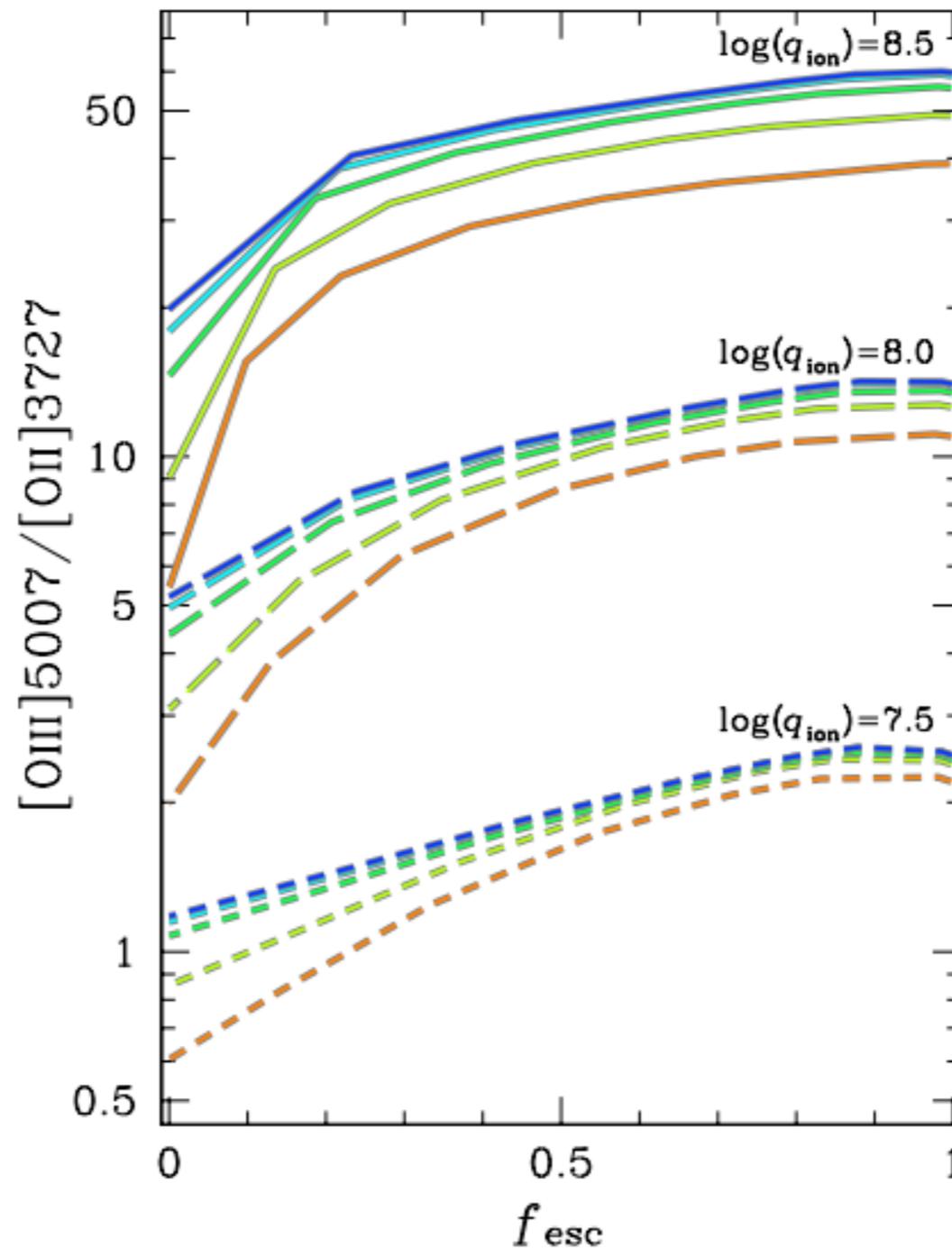
OI+SIII CII 1334 ?
1303

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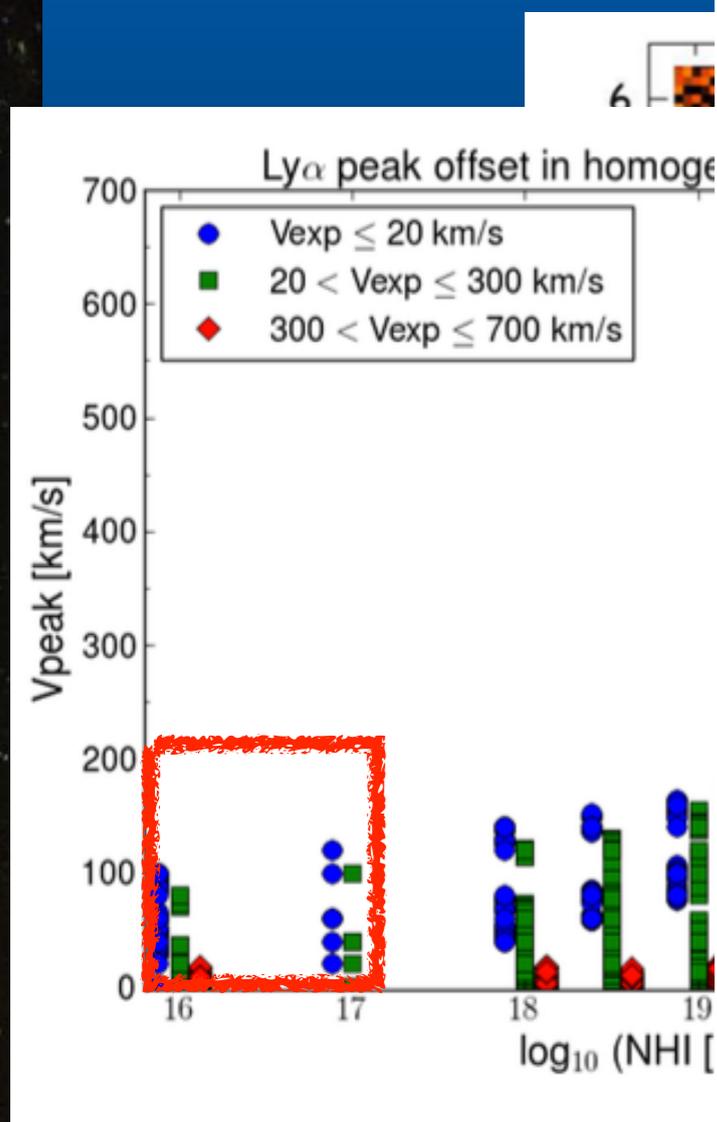
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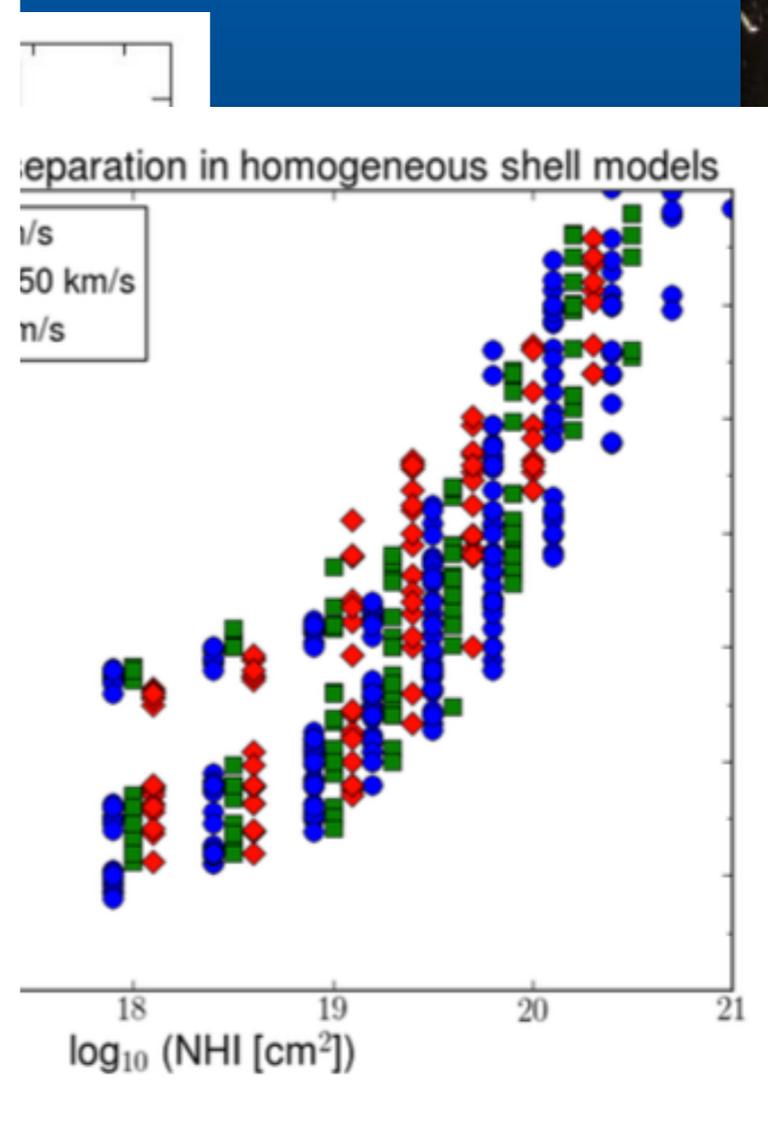
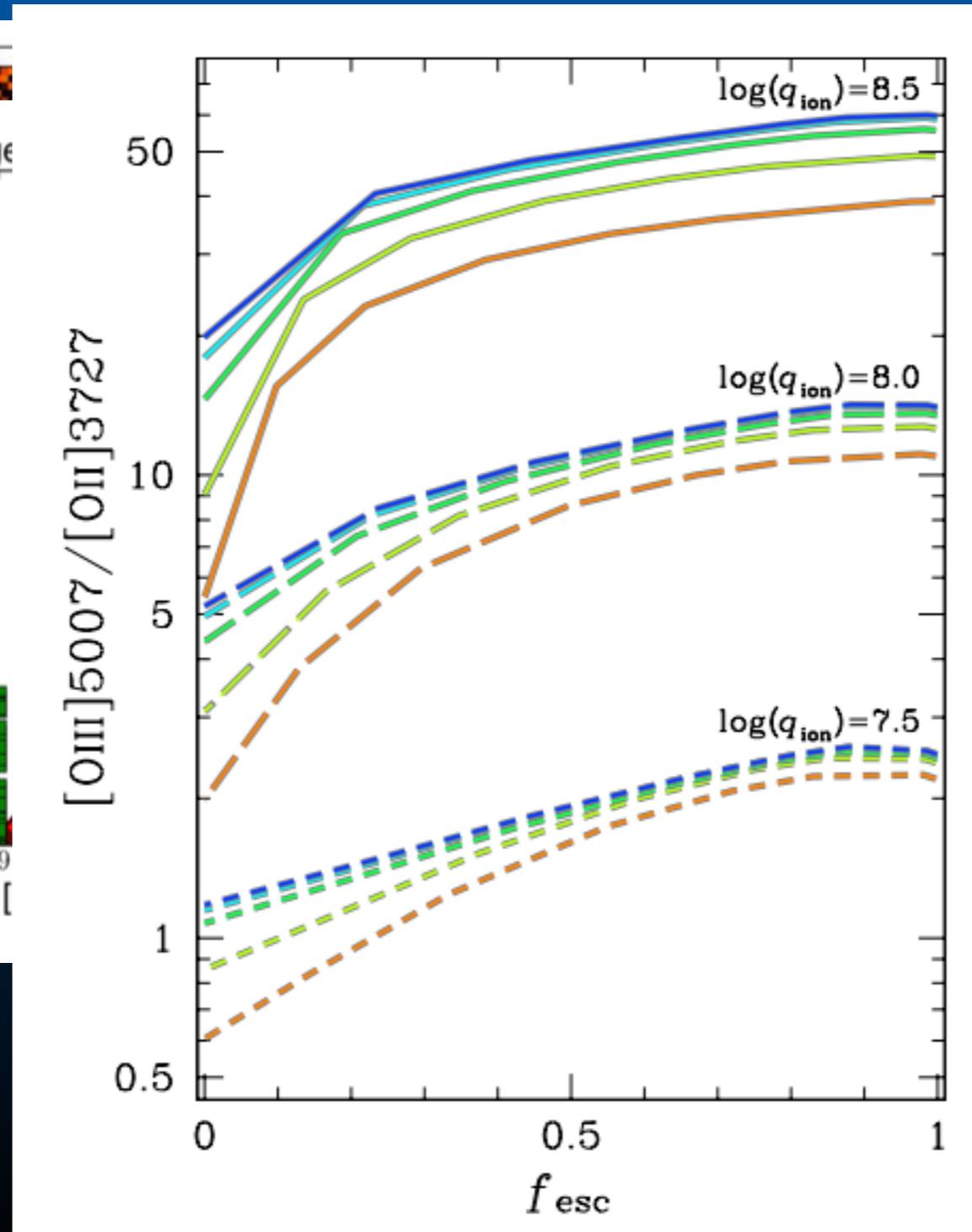
H β 1260
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 Nakajima & Ouchi 2014

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Verhamme+14

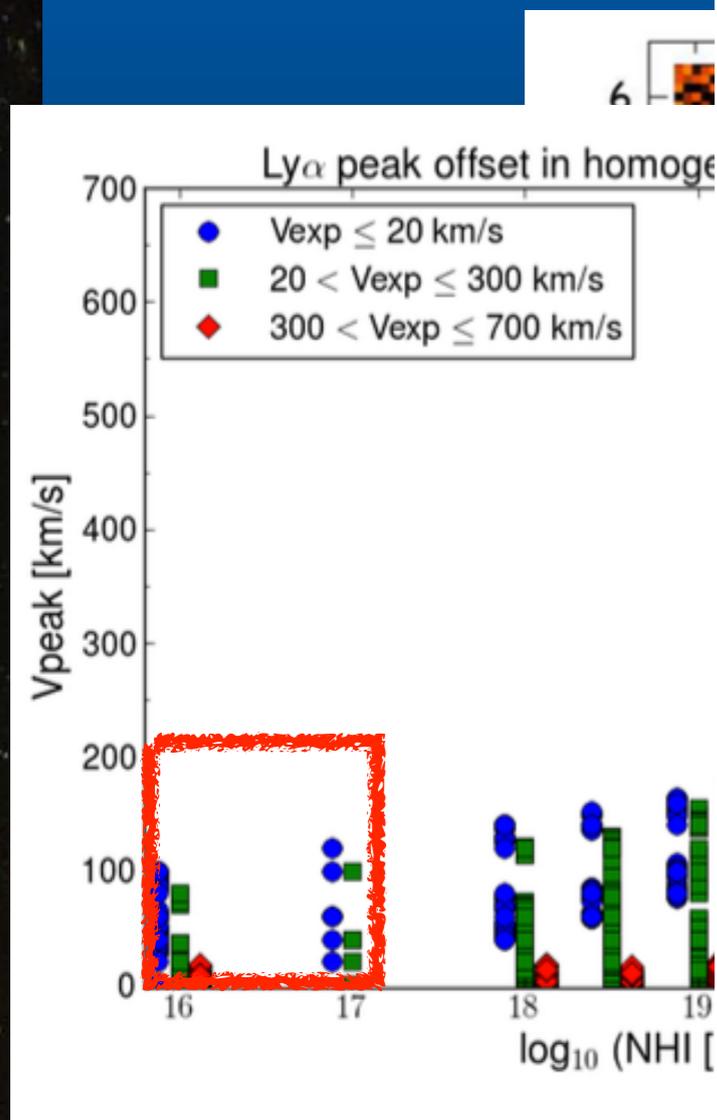


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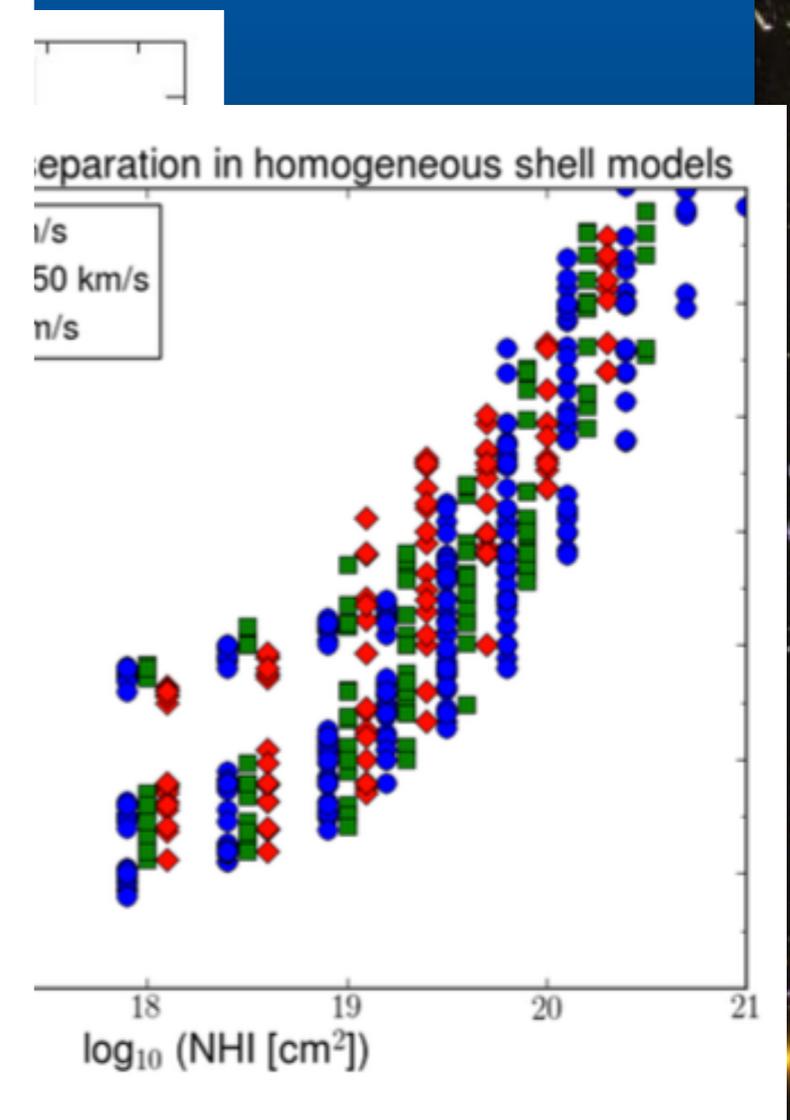
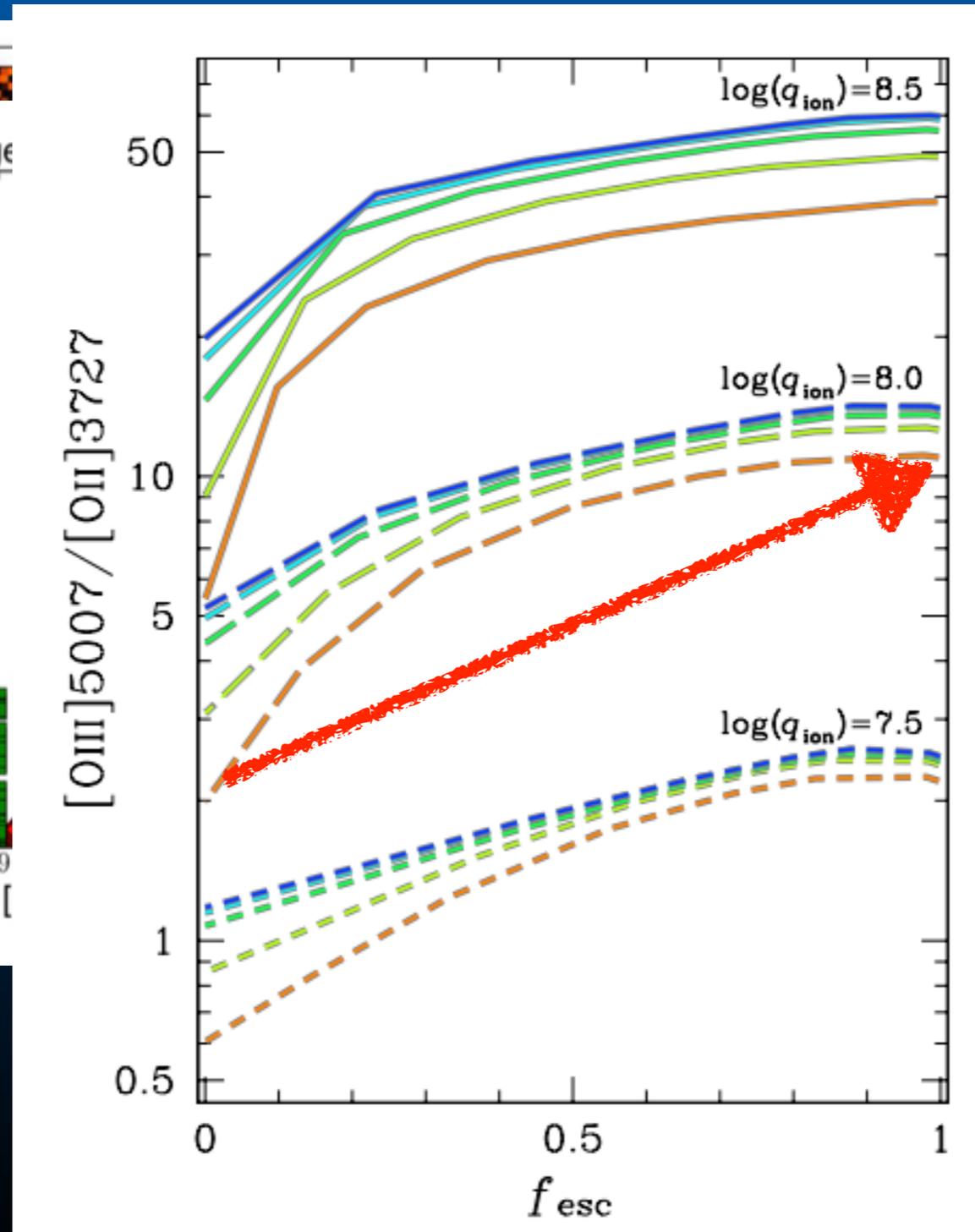
See also Daniel Schaerer Talk

Ion2: a plausible high-redshift Lyman continuum emitter

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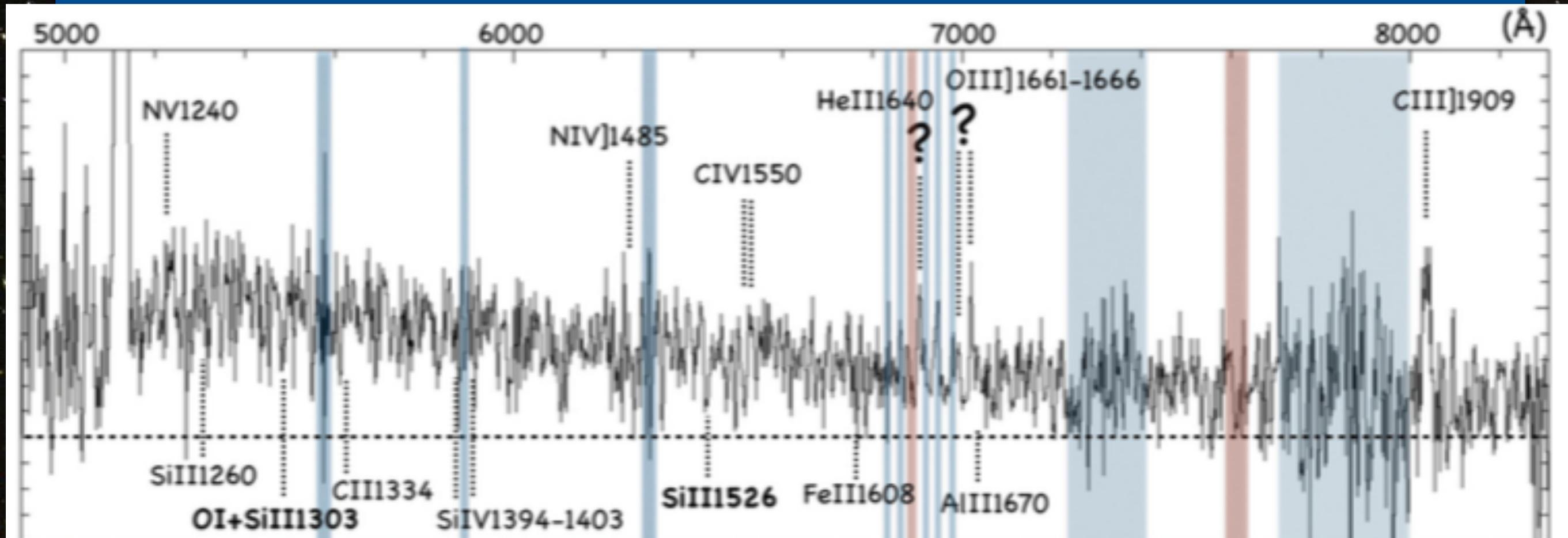
Verhamme+14



See also Daniel Schaerer Talk

Ion2: a plausible high-redshift Lyman continuum emitter

Selection, indirect evidence, direct evidence:



Low ionization emission lines: not detected
=Low neutral hydrogen column density (Jones+12,13)

Si III
OI+Si III
1303
C II 1334 ?

Ion2: a plausible high-redshift Lyman continuum emitter

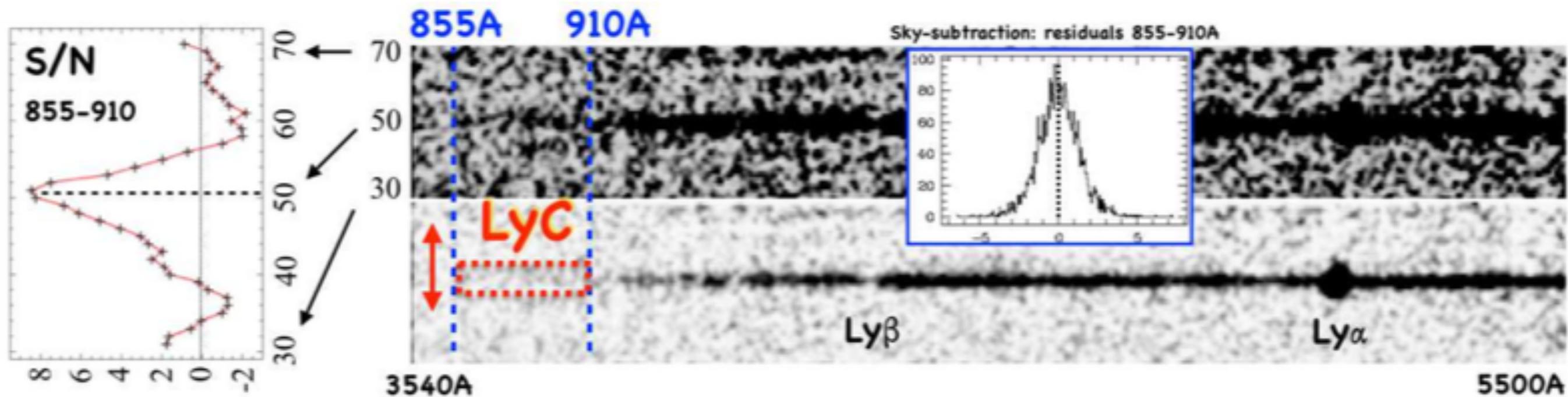
Strong OIII emission: is there an AGN contribution?

- No X-ray detection (6Ms Chandra), soon 10Ms Chandra
- Not detected in MIPS24
- No broad lines (e.g., OIII: 65km s^{-1})
- Obscured AGN (Vignali+2010): no CIV emission line
- Typical ratio: CIII/CIV ~ 0.5 and CIV/HeII > 1 for AGN, while for Ion2 > 10 and < 1 , respectively
- CIII/CIV ratio related to nature of ionizing source (Binette +2003): ratio consistent with pop I stars
- Spatially resolved in all ACS bands

IF it is an AGN, still interesting: how many “faint & obscured” AGN like this one at high-z?

Ion2: a plausible high-redshift Lyman continuum emitter

Selection, indirect evidence, direct evidence:



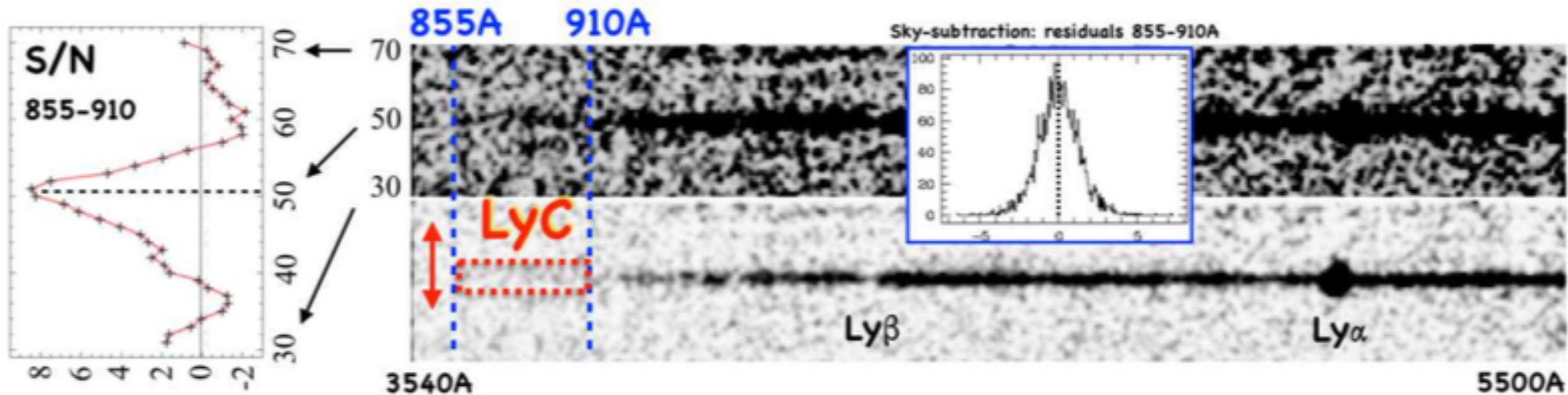
De Barros+15

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OI+SIII 1303
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De Barros+15

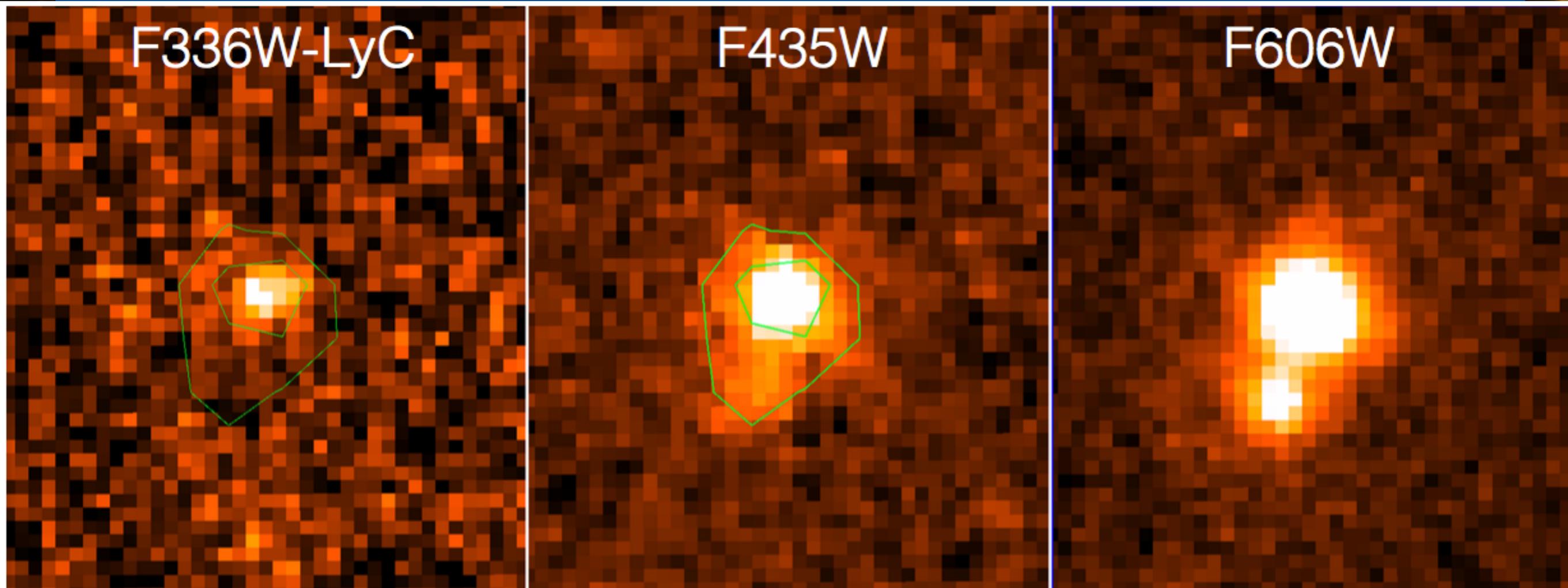
HST program (PI: E. Vanzella): 17 orbits

SIII 1260

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Ion2: a ~~plausible~~ high-redshift Lyman
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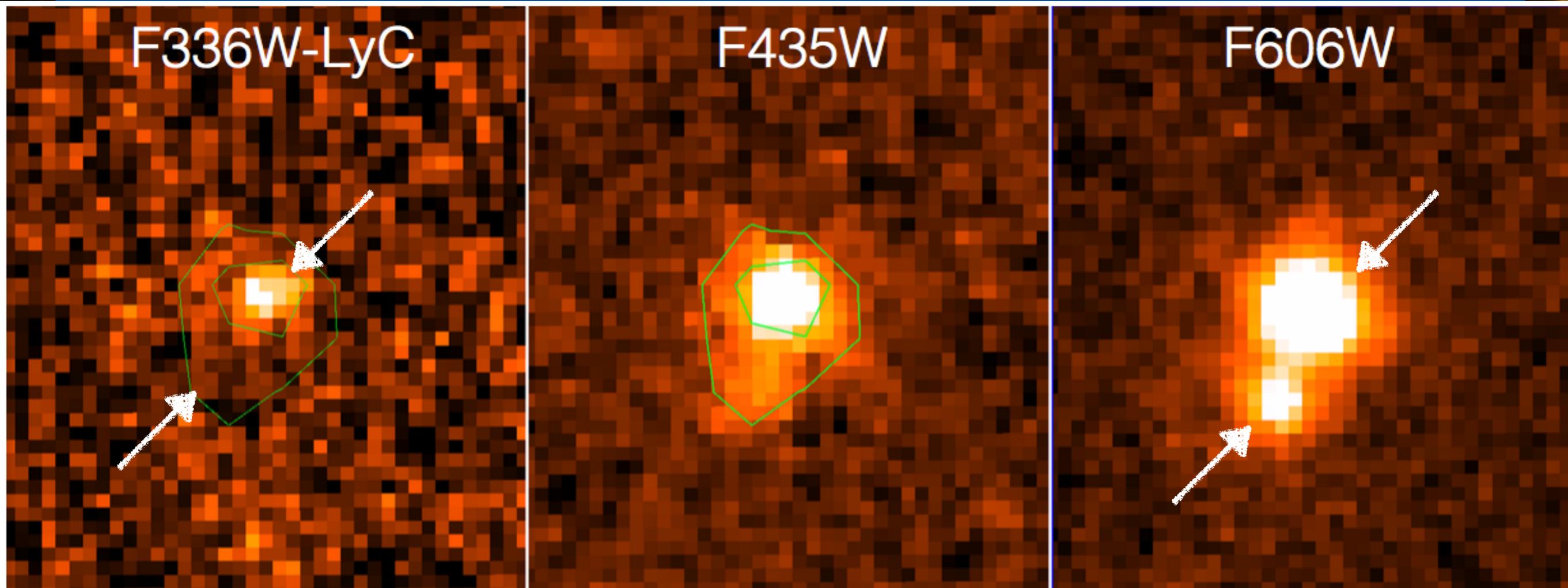
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First high spatial resolution image of LyC emission

SIII 1260
OI+SIII
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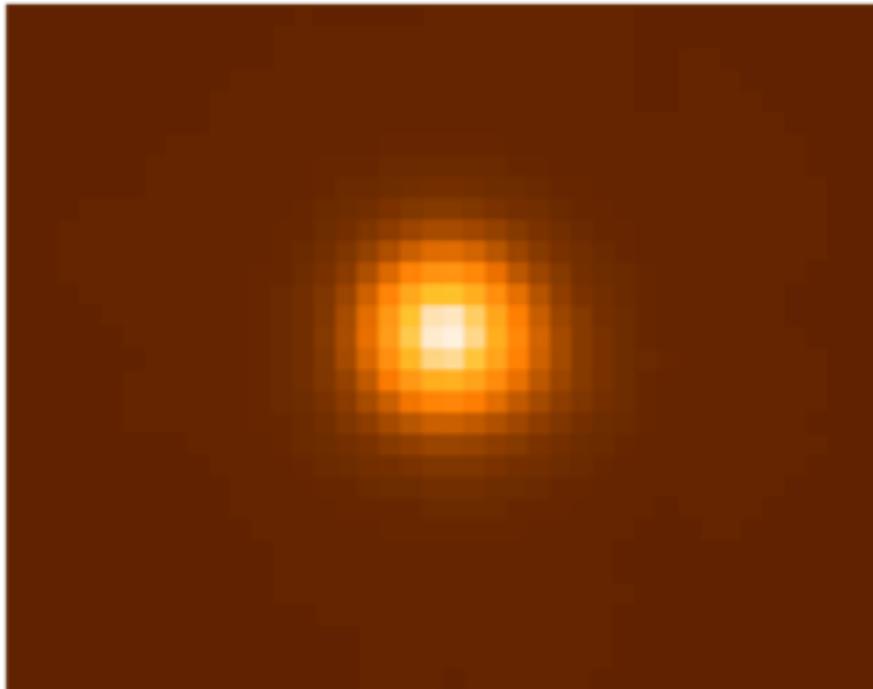
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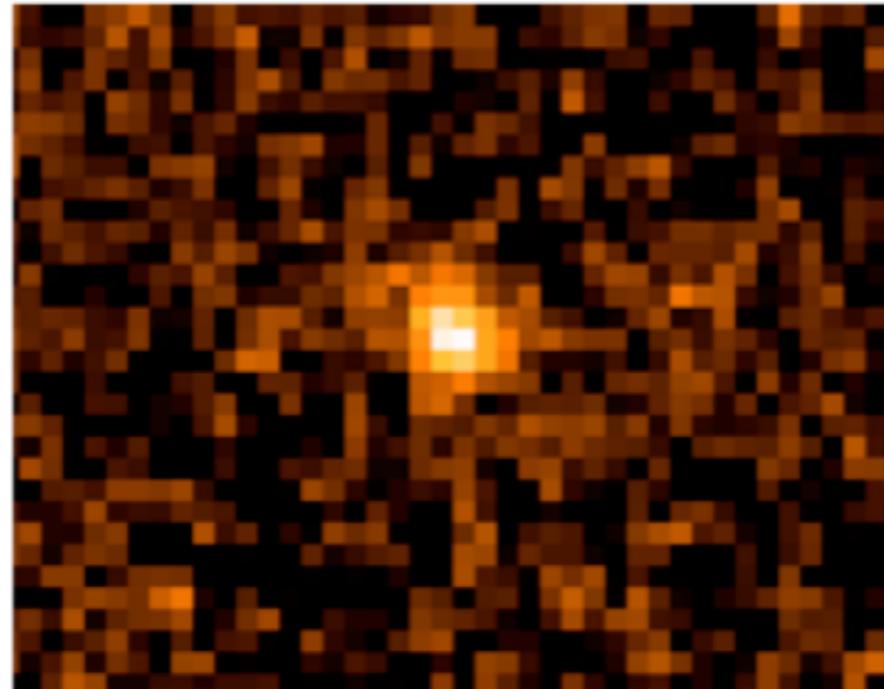
A

B

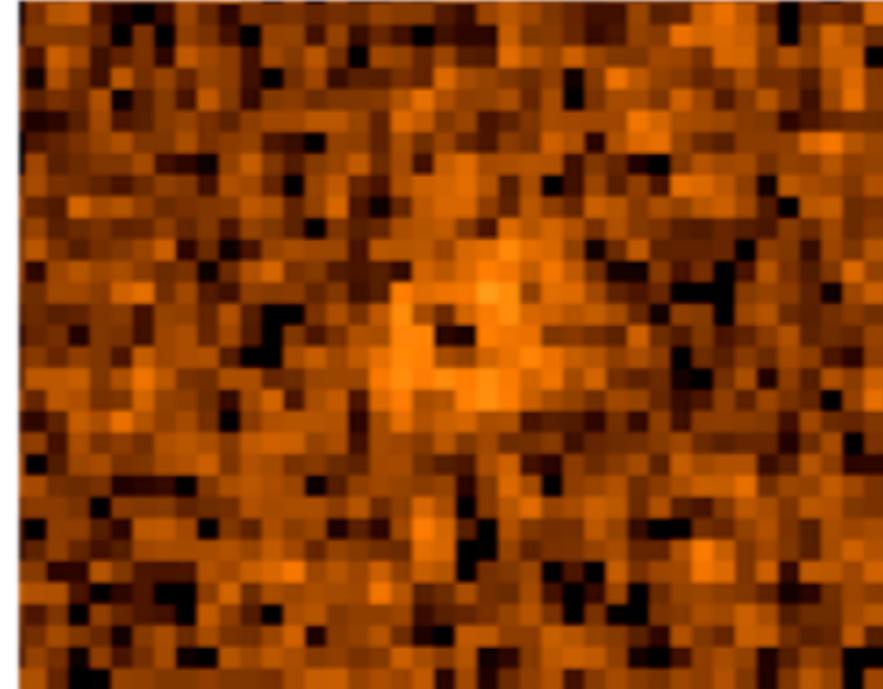
A-B



F435W (model)



F336W (observed)



Can not conclude

HST program (PI: E. Vanzella): 17 orbits

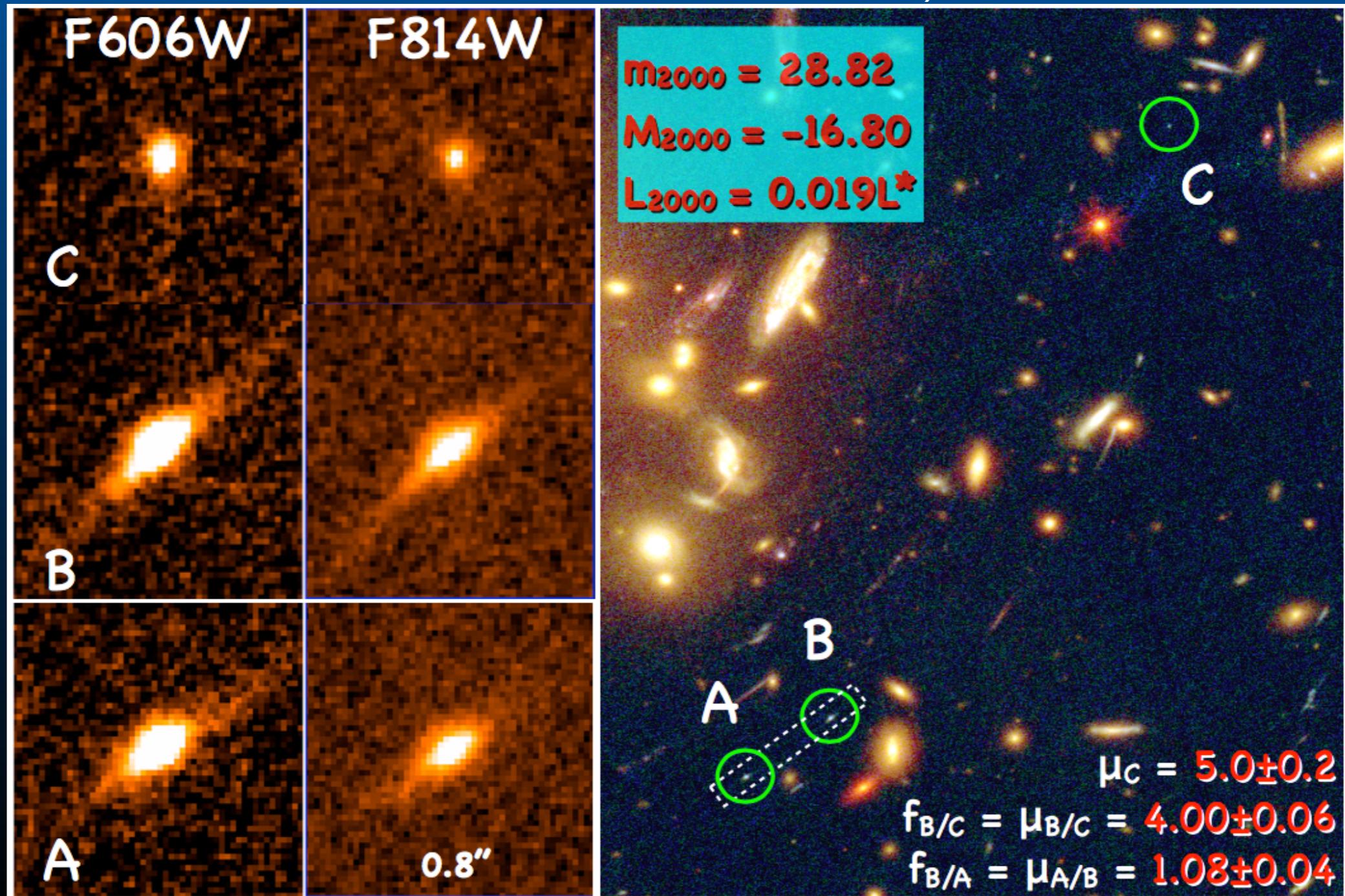
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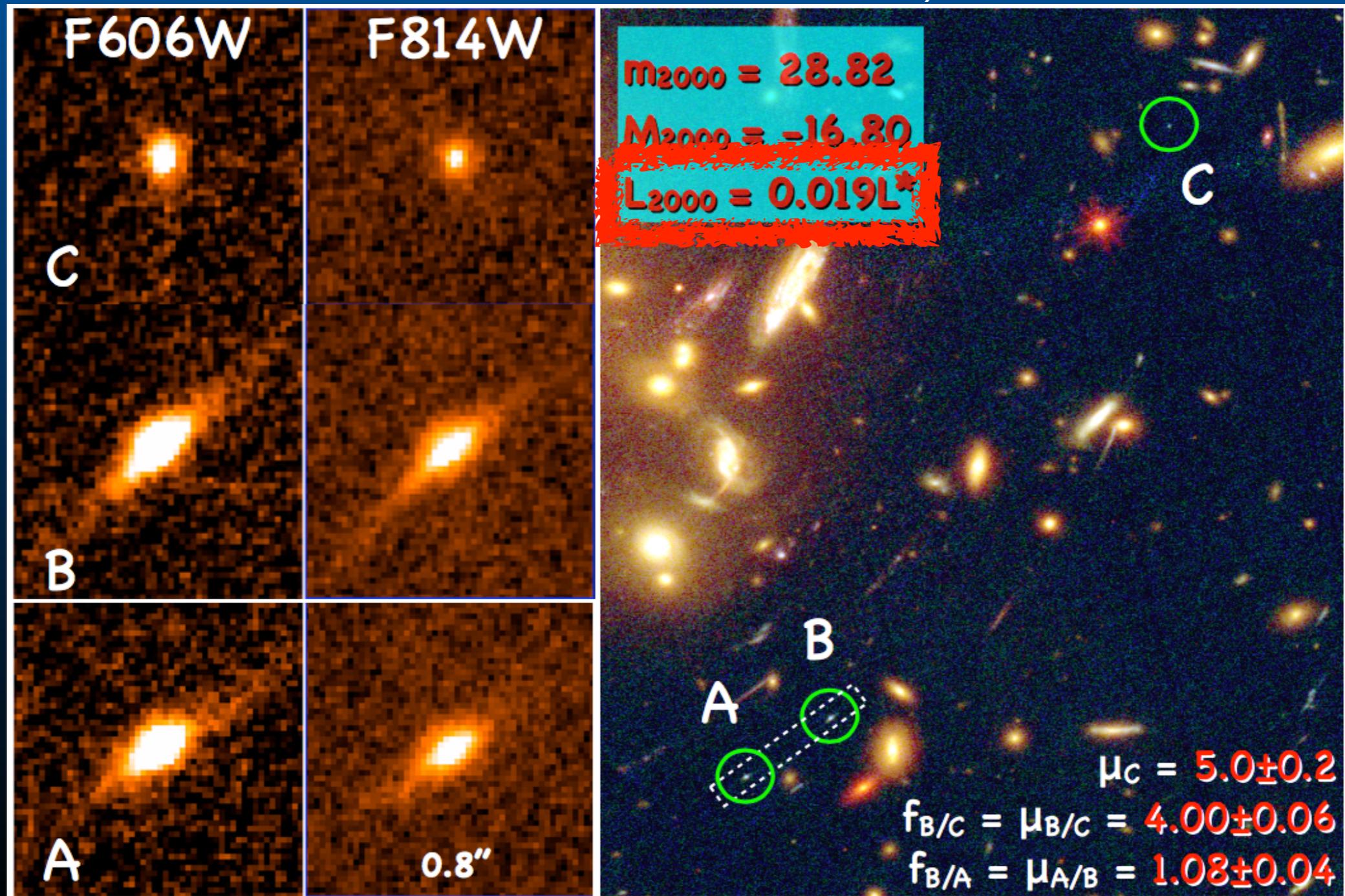
A low-luminosity LyC candidate at z=3.1 in the Frontier Fields

Is this working for faint galaxies (main contributors to cosmic reionization)?



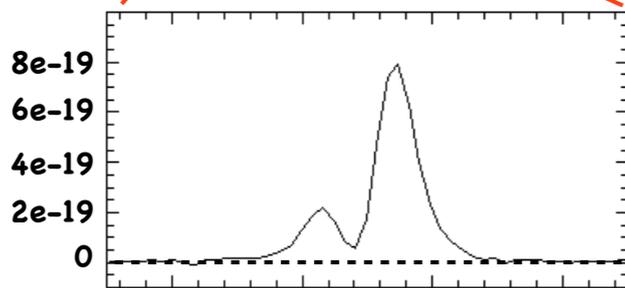
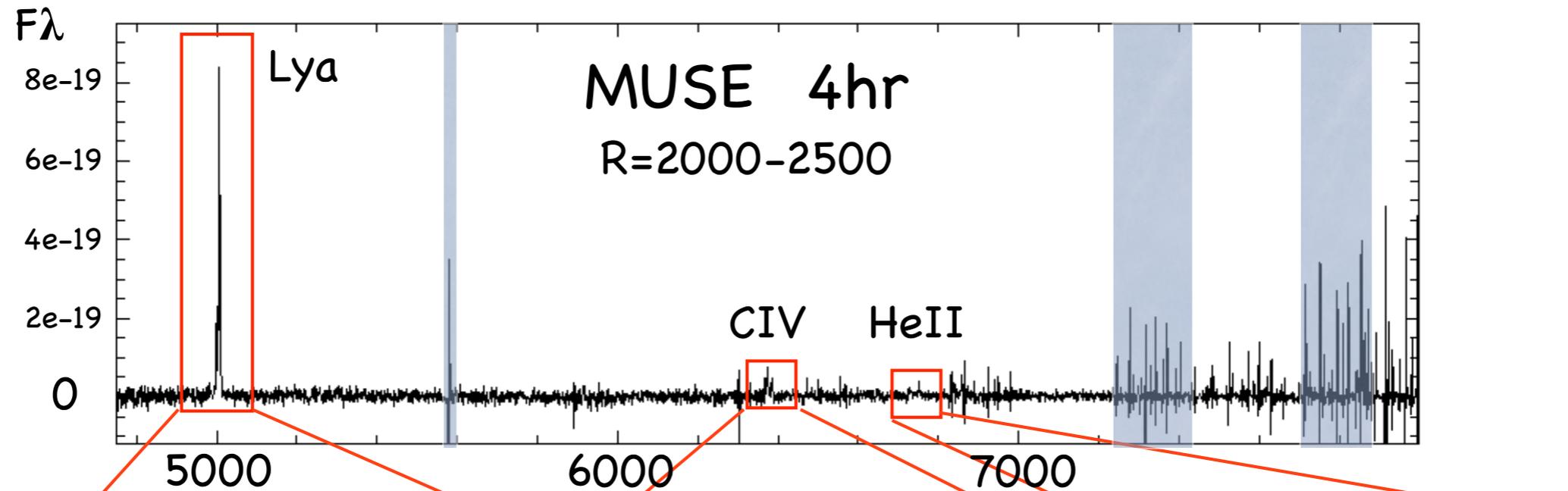
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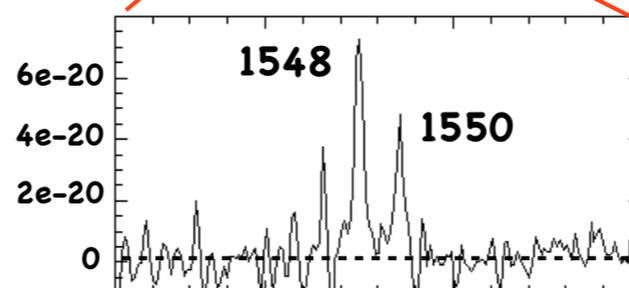
Vanzella+16 in prep

A low-luminosity LyC candidate at $z=3.1$ in the Frontier Fields



Ly α 1215.7

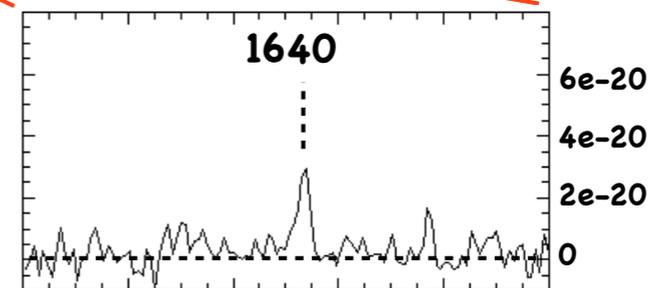
$3.2e-18, 7.0e-19$ cgs



CIV 1548-1551

$2.4e-19, 1.4e-19$ cgs

sigma < 50 km/s

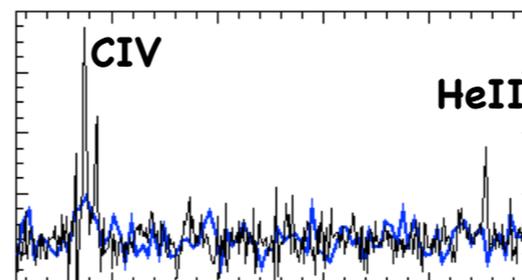


HeII1640

$9.0e-20$ cgs

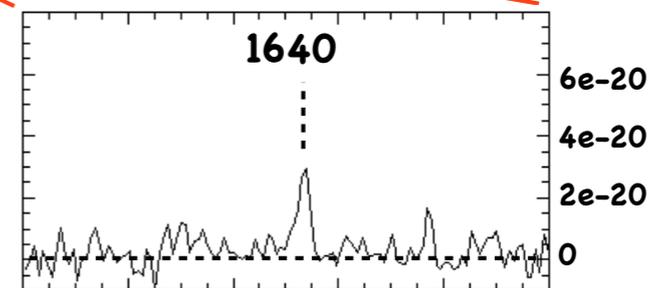
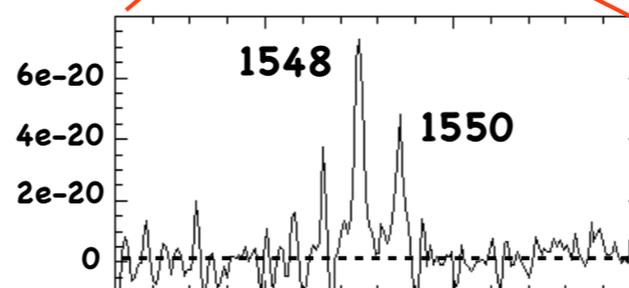
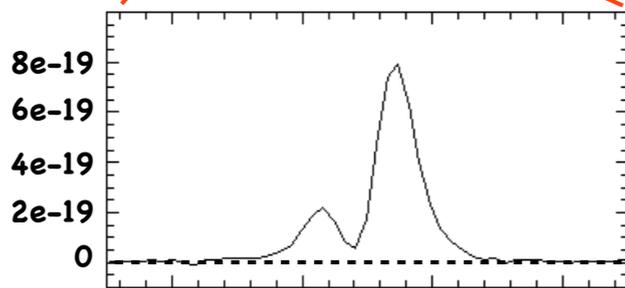
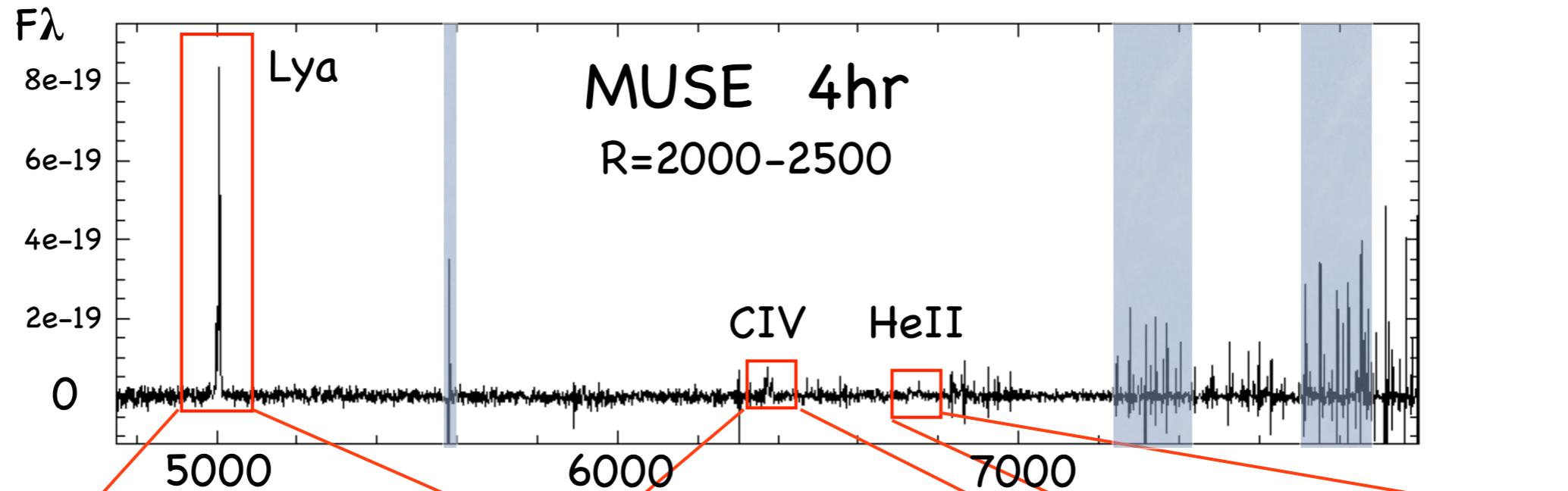
sigma < 50 km/s

Karman et al. (2014+in prep)
Vanzella in prep.



— MUSE
— VIMOS LR

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CIV 1548-1551

HeII 1640

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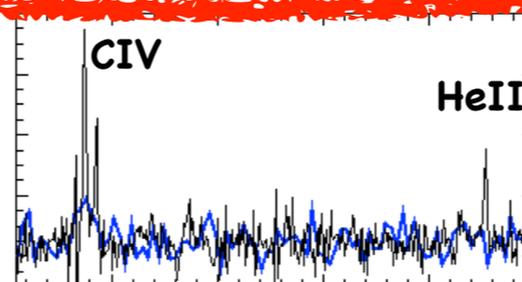
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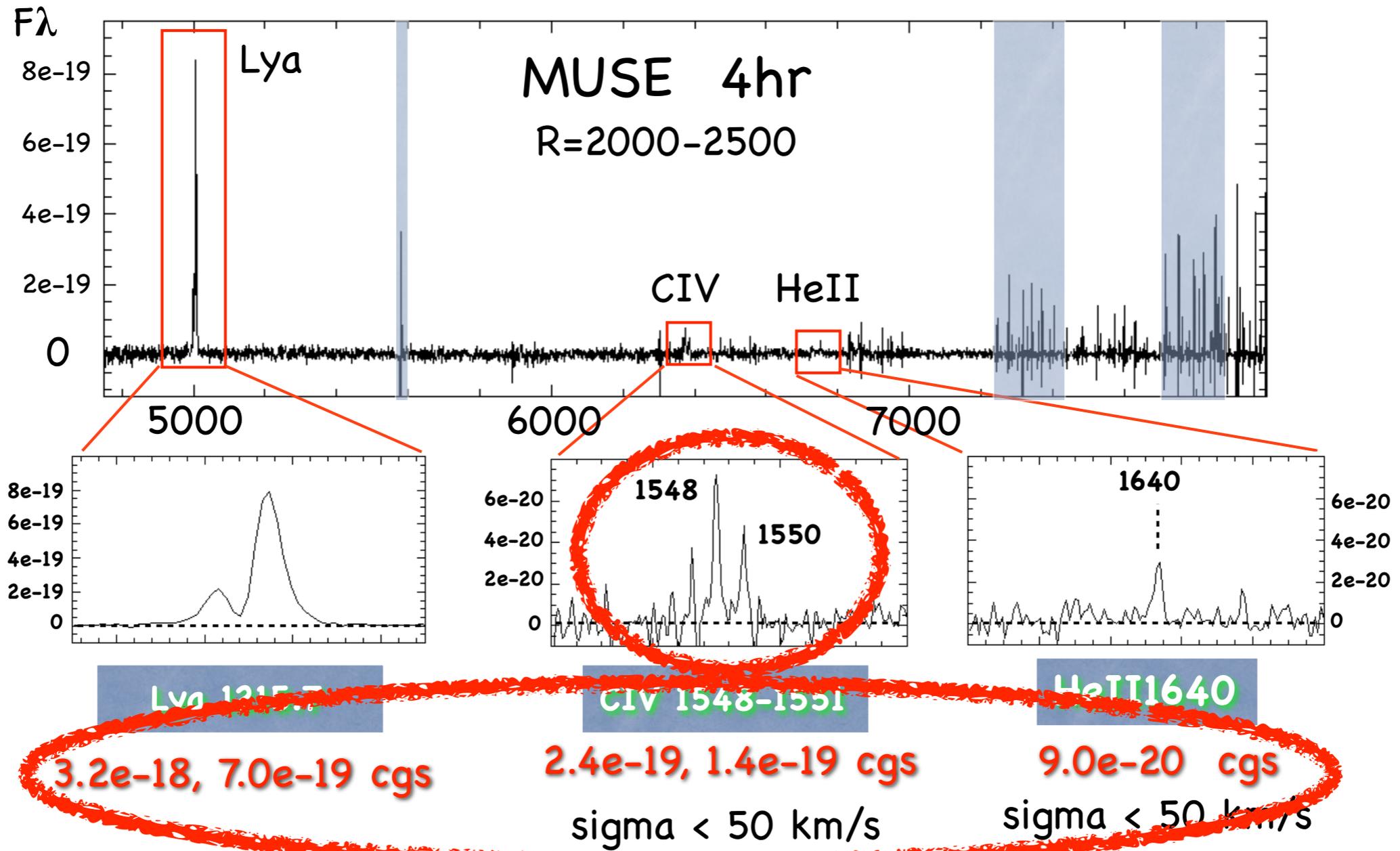
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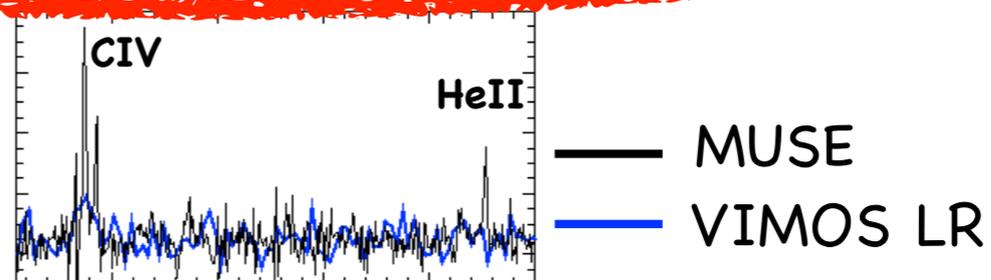


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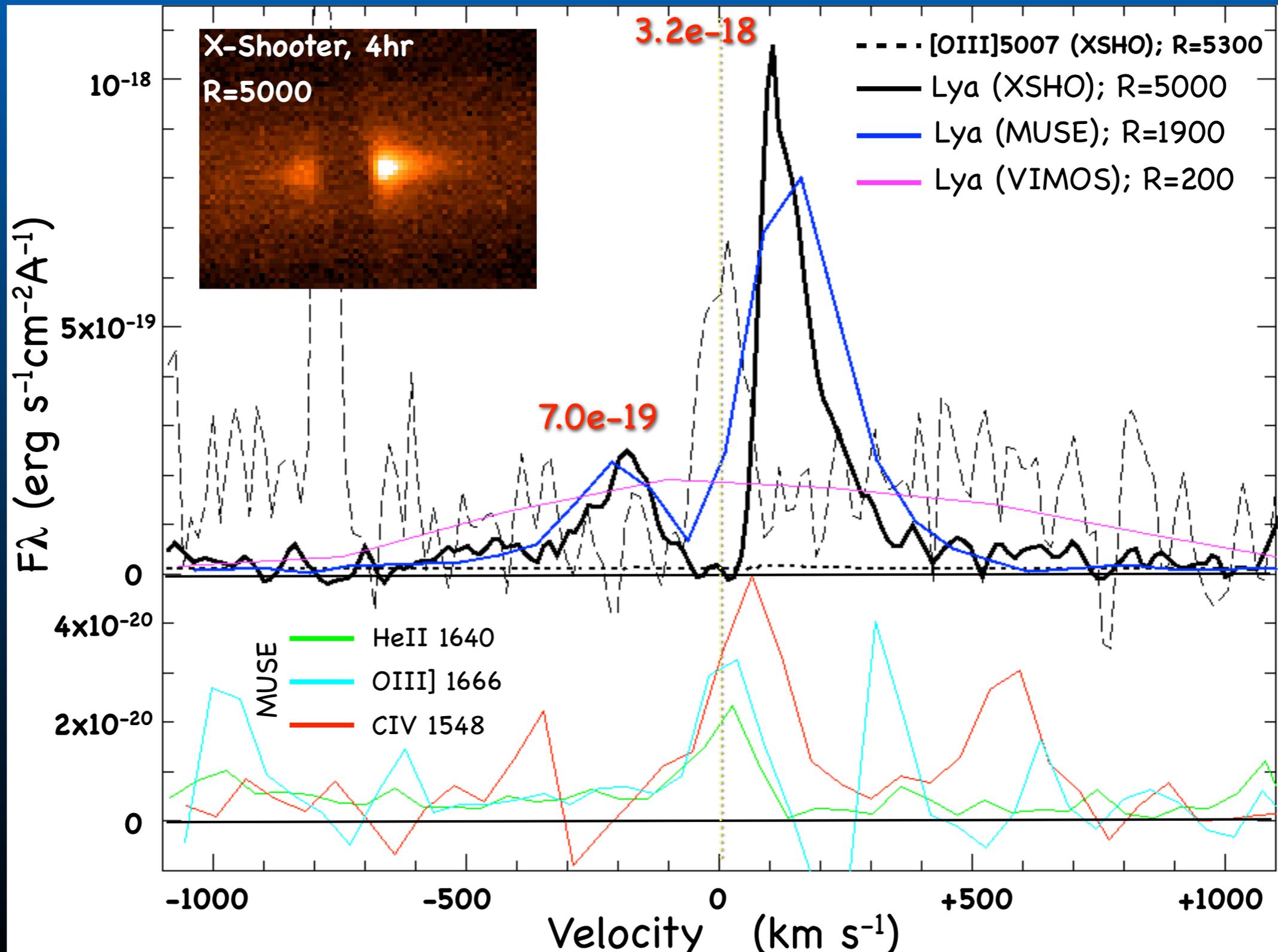
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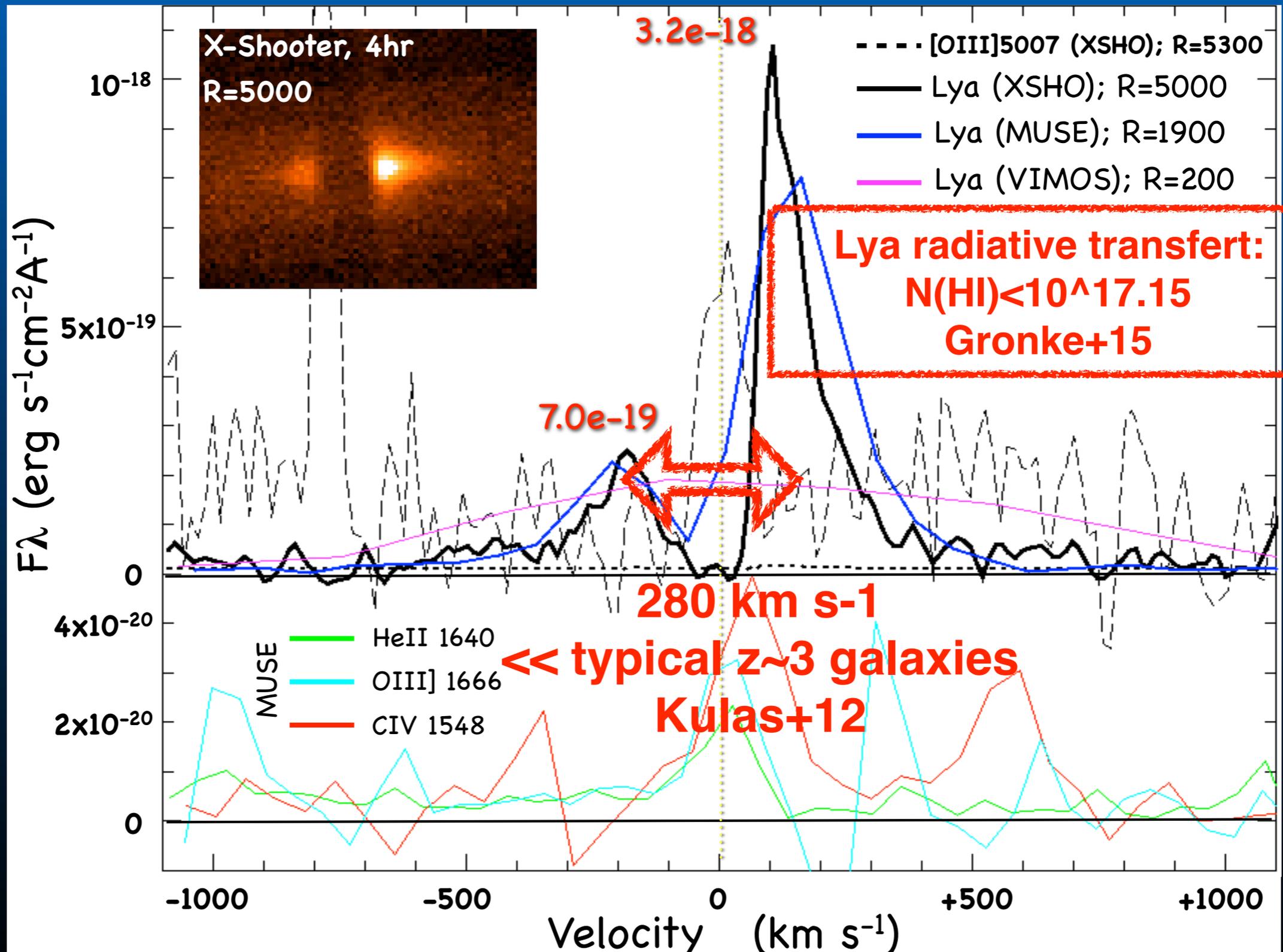
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A low-luminosity LyC candidate at $z=3.1$ in the Frontier Fields



A low-luminosity LyC candidate at $z=3.1$ in the Frontier Fields

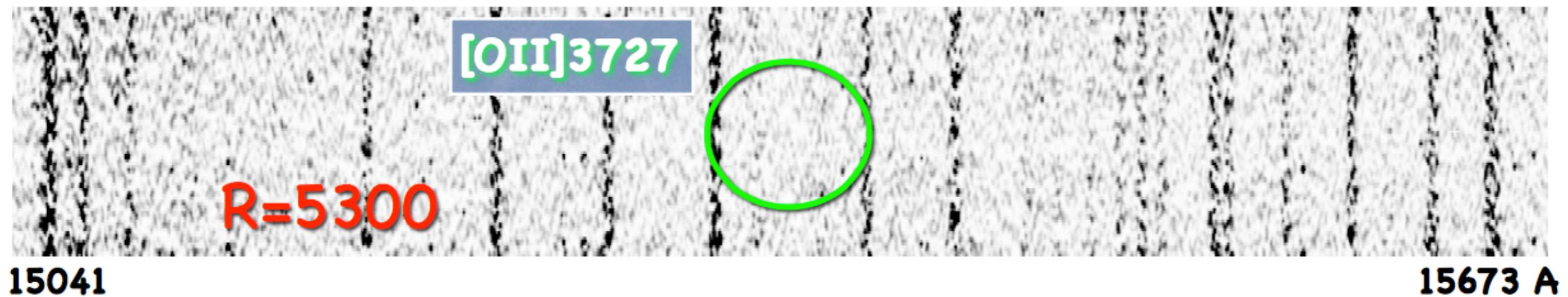
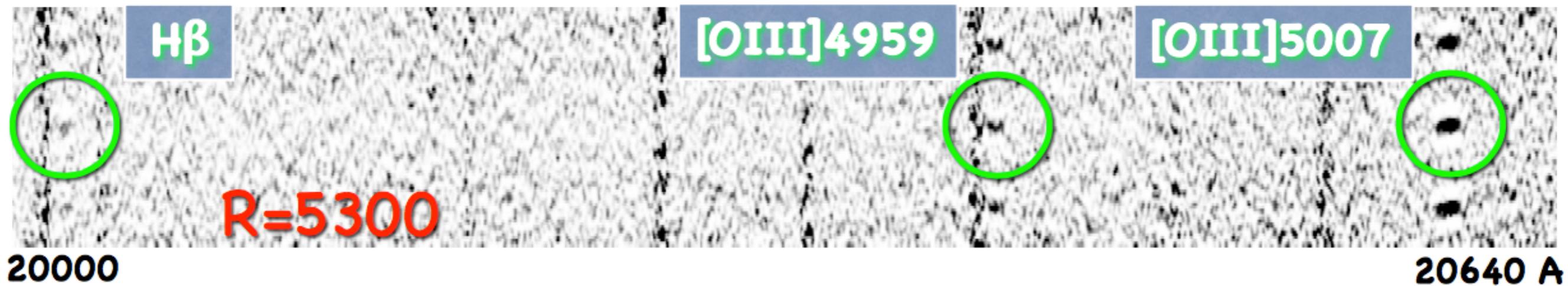


A low-luminosity LyC candidate at z=3.1 in the Frontier Fields

An E-ELT flavor: mag=28.83

X-Shooter

Vanzella in prep.



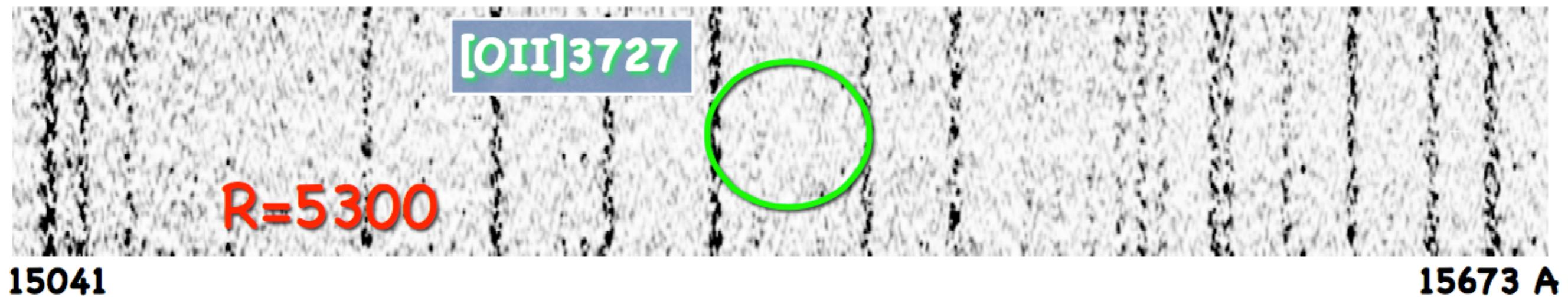
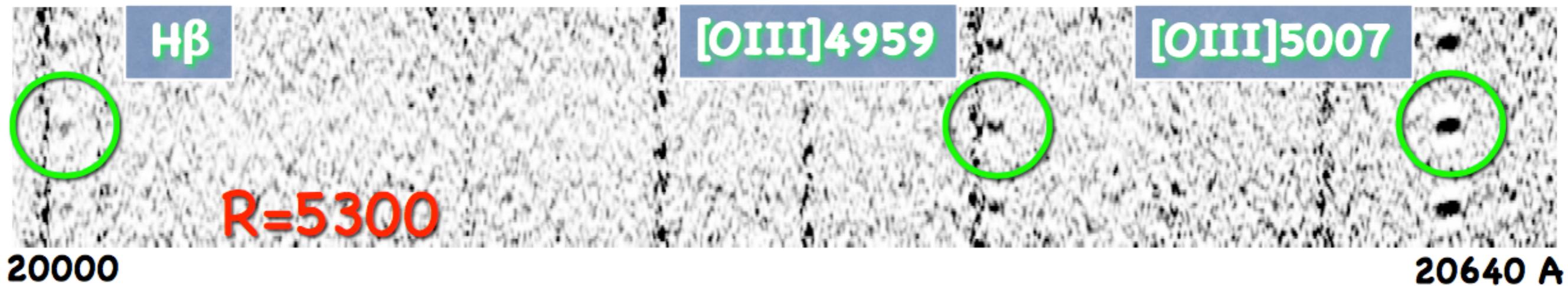
SiII 1205
OI+SIII CII 1334 ?
1303

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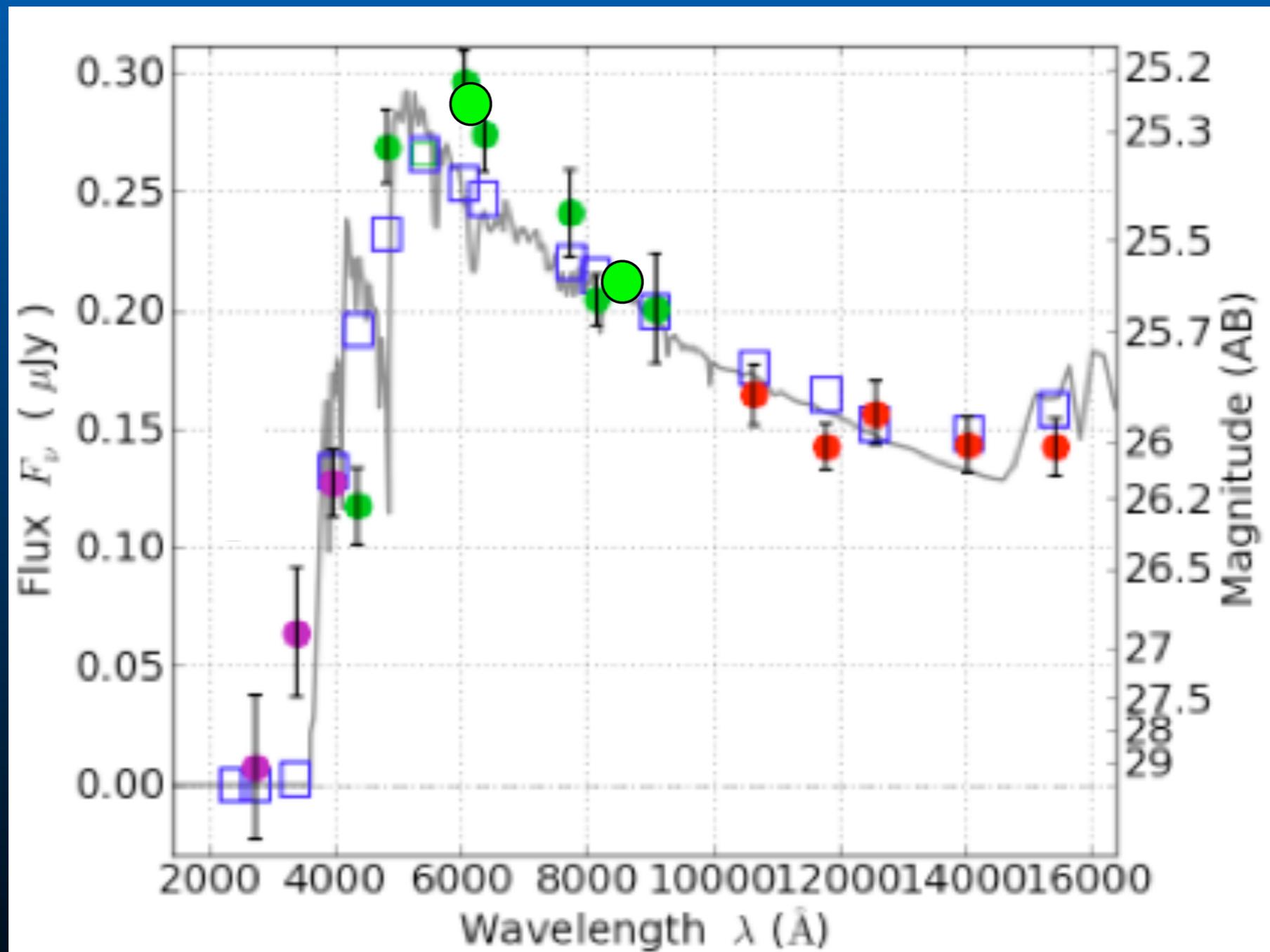
Vanzella in prep.



$OIII/OII \sim 10!$

$SII 1209$
 $OI+SIII 1303$
 $CII 1334 ?$

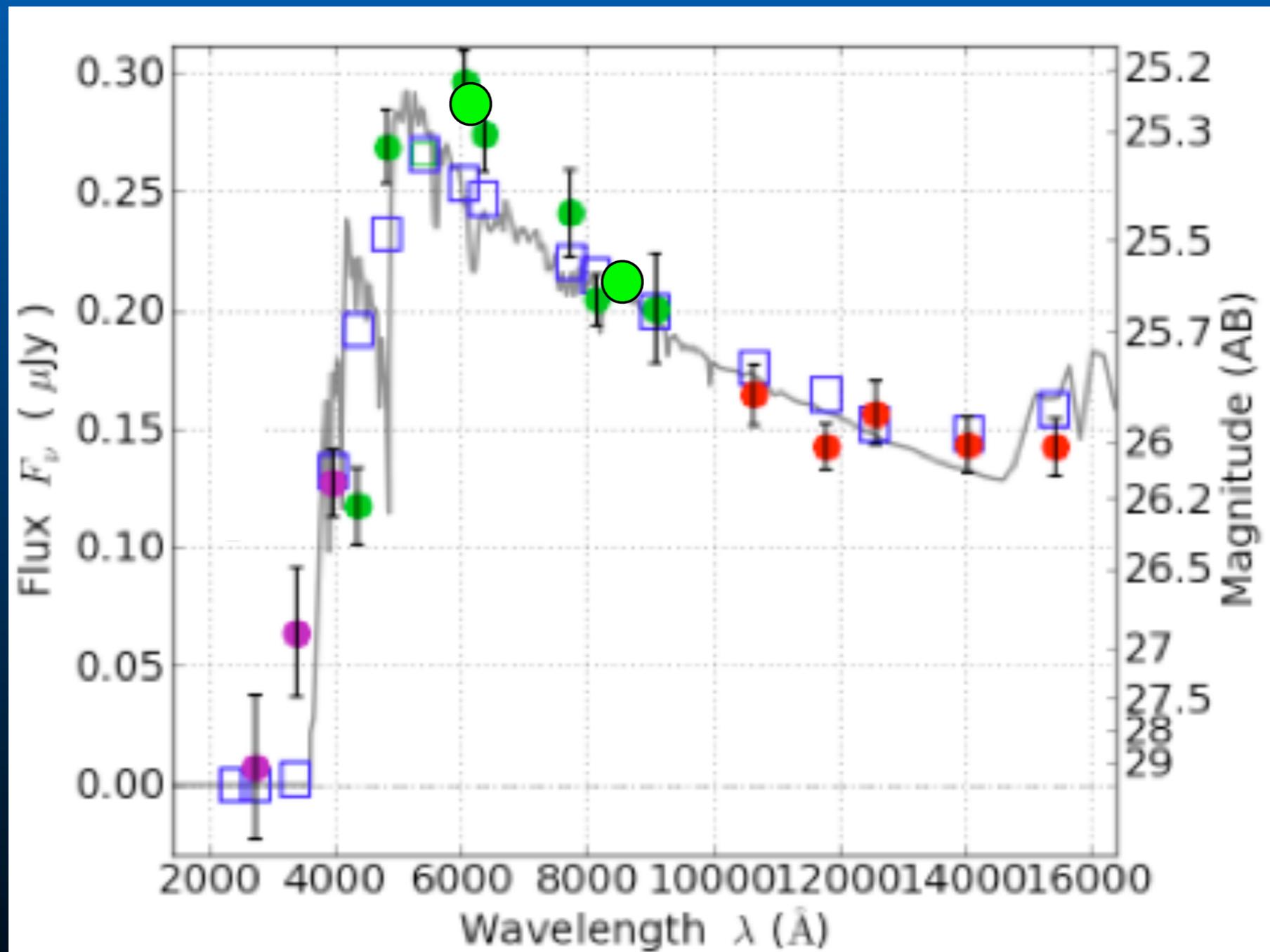
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SIII 1260

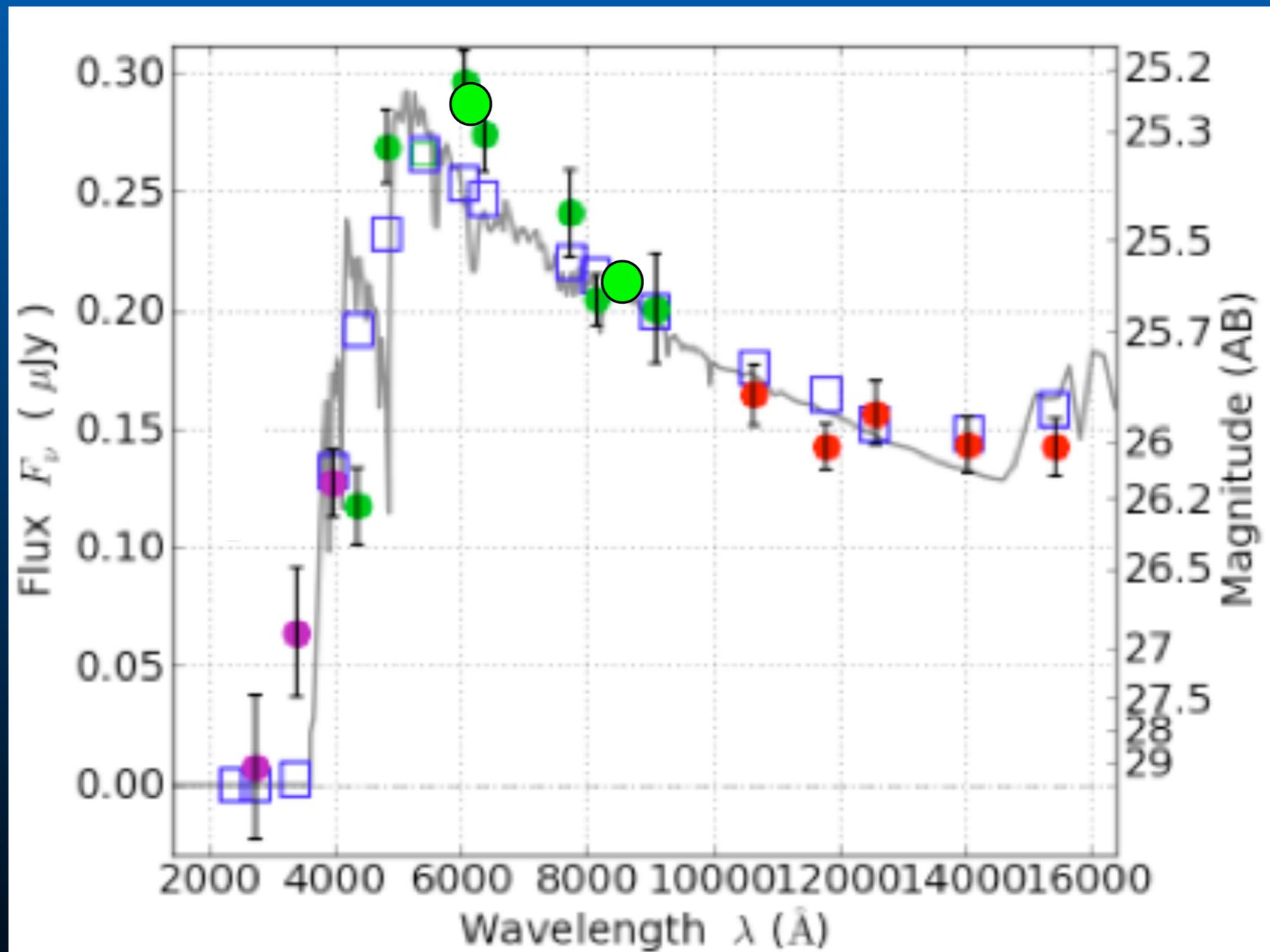
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A low-luminosity LyC candidate at $z=3.1$ in the Frontier Fields



UV slope < -2.6 similar to $z=6.4$ HFF M0717 (Vanzella+14)

A low-luminosity LyC candidate at z=3.1 in the Frontier Fields



UV slope < -2.6 similar to z=6.4 HFF M0717 (Vanzella+14)

HST program (PI: B. Siana): LyC detection?

Conclusions

Spectroscopy can be used:

- To characterize galaxies at the time of cosmic reionization
- To search for high-redshift leakers ($z < 4$), to study leakage processes and signatures
- Lot of data at $z \sim 6$ (and $z \sim 7$): signature of strong OIII emission difficult to found
- We found a LyC emitter at $z \sim 3.2$ (1 Gyr from cosmic reionization): similar $EW(OIII+HB)$ as $z \sim 6-7$, several proposed leakage signatures confirmed, **first high spatial resolution image of LyC emission**
- Good candidate in the faint regime ($0.02L^*$): high-redshift ionizer analog?

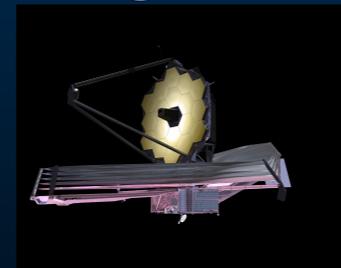
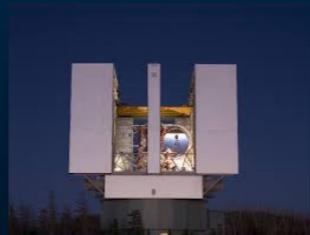
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In the future

In few weeks: *Probing cosmic reionization through a magnifying GLASS, LBT/LUCI, PI: De Barros*

In the less near future: JWST (lines from $z \sim 6-7$ galaxies and from $z \sim 3$ leakers)... but need HST to confirm leakage and morphology!

SIII 1260

OI+SIII CII 1334 ?

1302