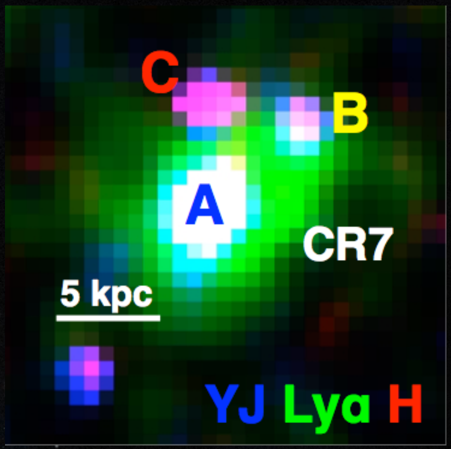
Search for Population III Stars with TMT/IRMS



Bahram Mobasher

University of California, Riverside

David Sobral, Jorryt Matthee, Sérgio Santos, Behnam Darvish, Daniel Schaerer, Huub Rottgering, Shoubaneh Hemmati

What is needed to search for pop III stars?

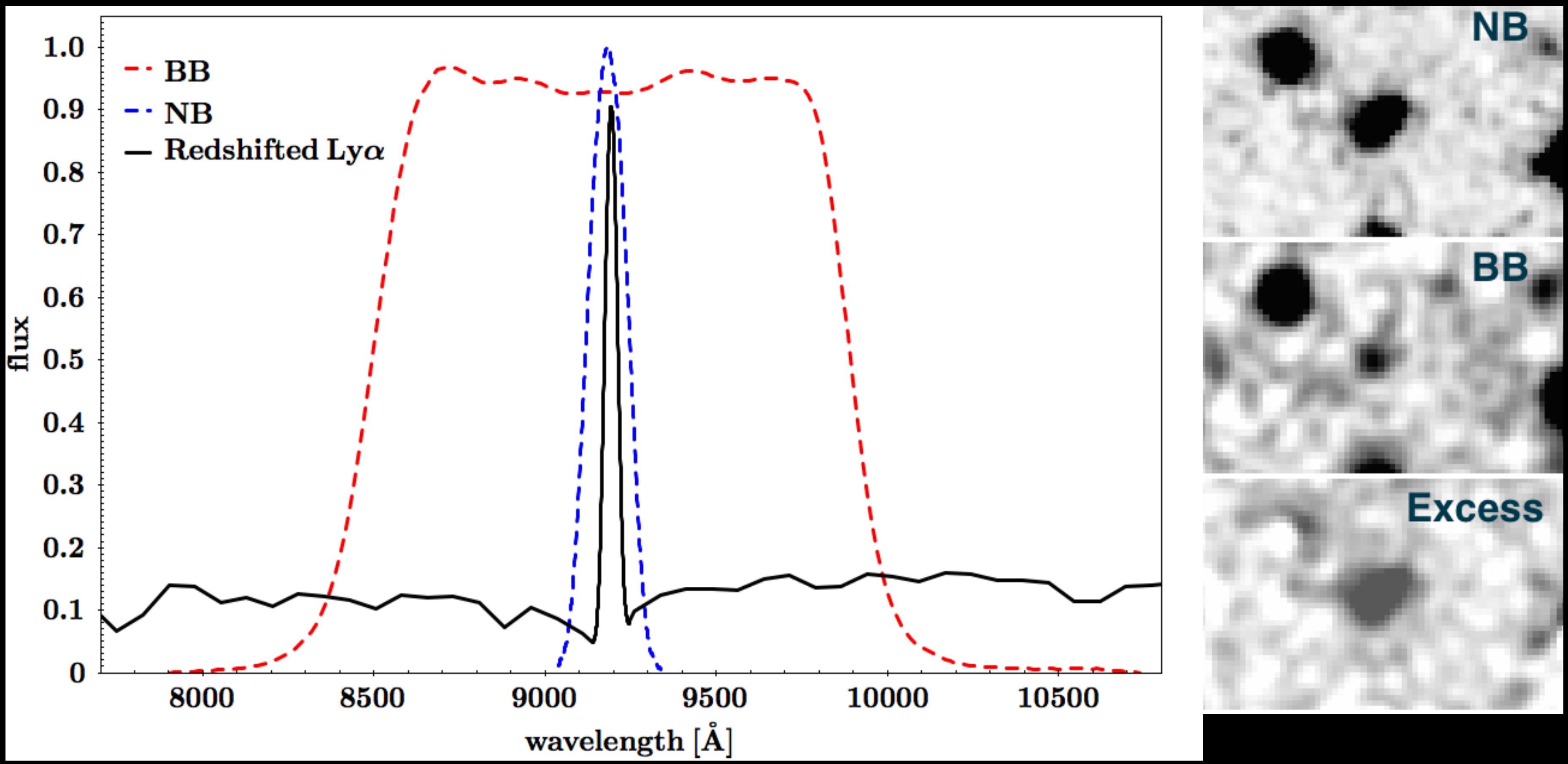
- Are we at the point to search for pop III stars ?
- With present instruments, could we make such observations?
- What samples do we need?

To search for Pop III stars we need:

- Strong Lyman alpha emission produced by young stars
- Evidence for HeII 1640 line (ionization potential ~54 eV)
- Absence of metal lines (eg. CIII] with ionization potential 48 eV)
- Need spectroscopy of faint high-z systems

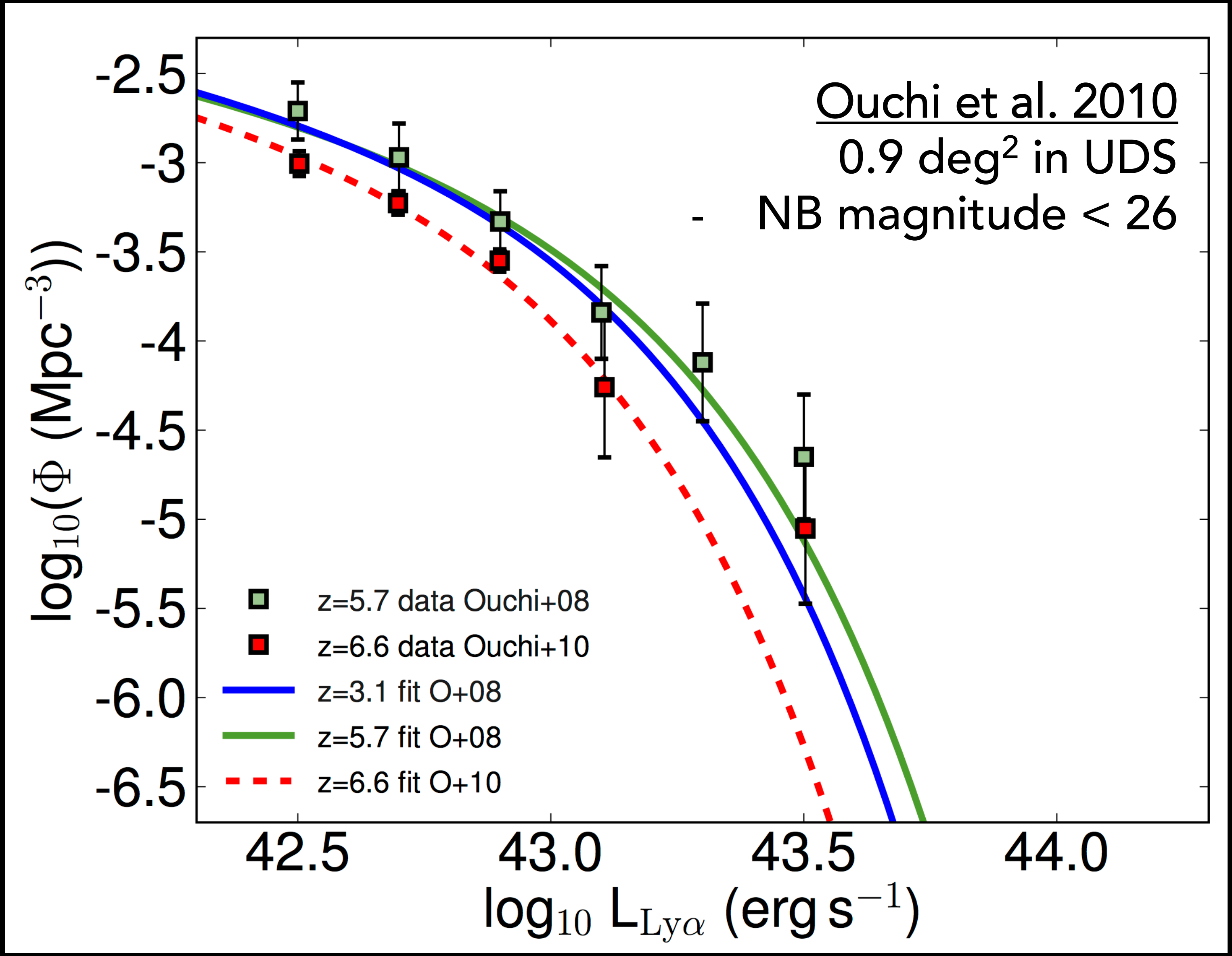
Lyman-α as a tool to study young galaxies and re-ionisation

narrow-band selects redshifted 1216 Å emission (optical at z>2)



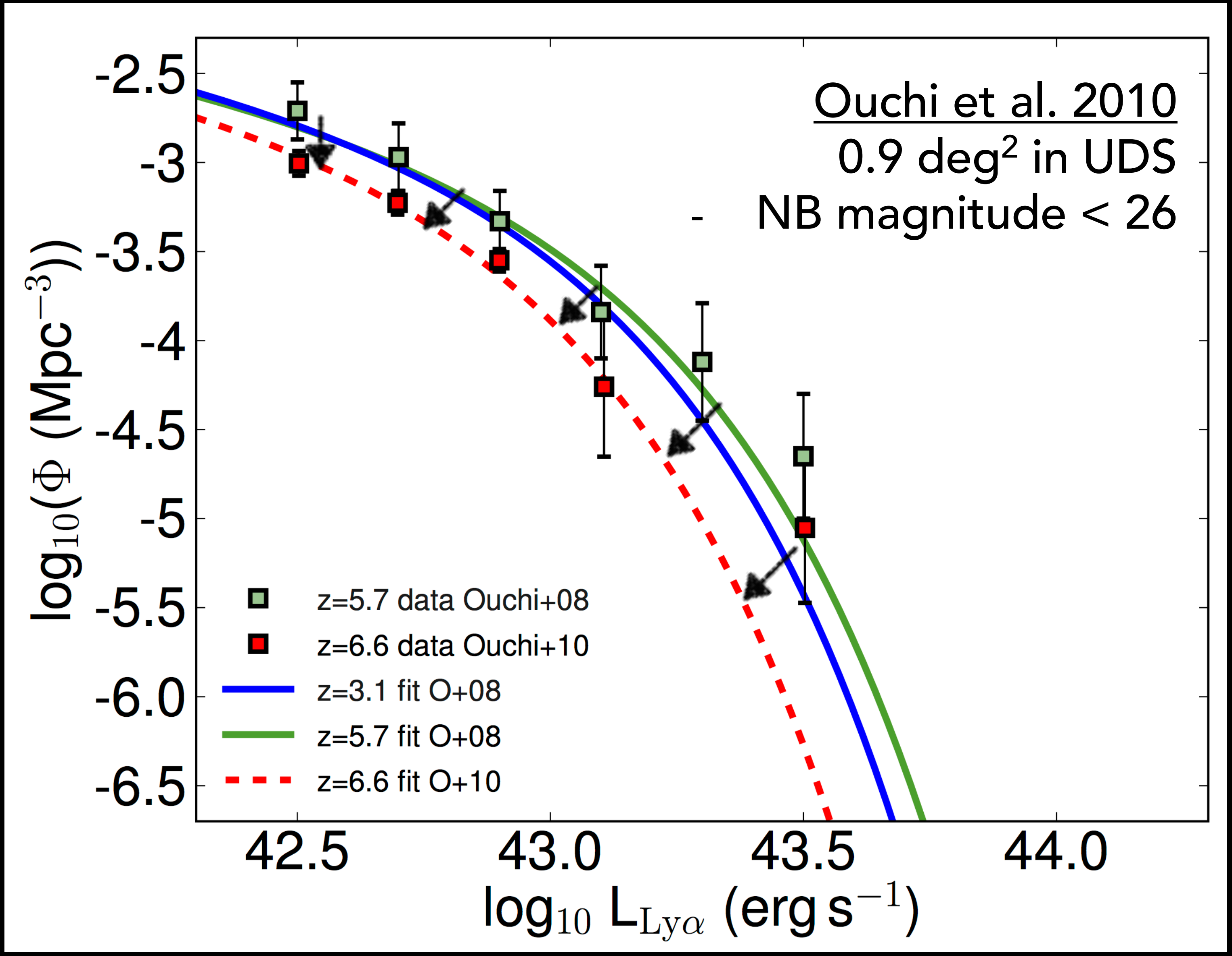
- Lyα emitted by young galaxies (high EW)
- Lyα absorbed in more neutral IGM (test for re-ionisation)

Lyman-α Luminosity function z~3-6 roughly constant



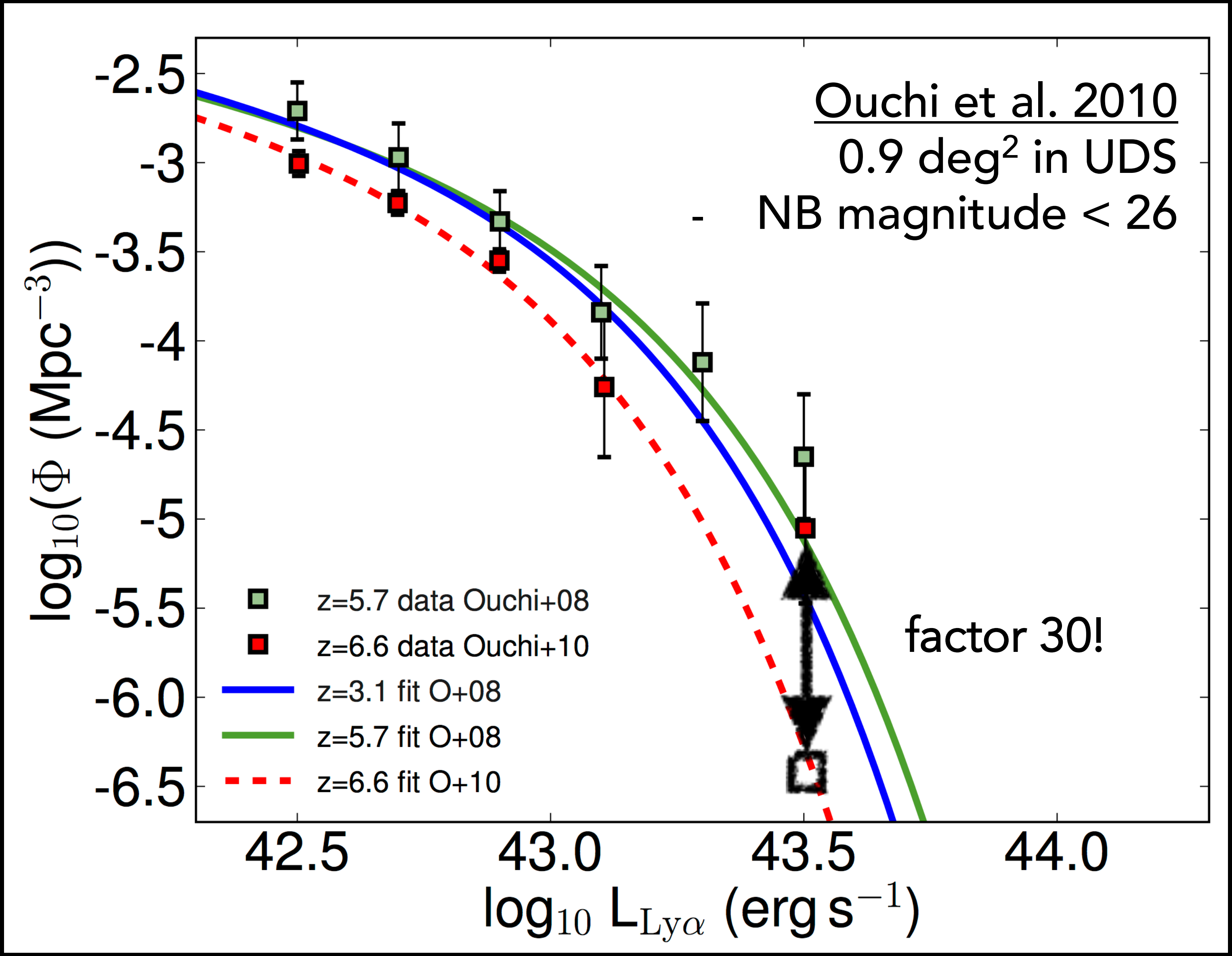
Lyman-α Luminosity function at z=6.6

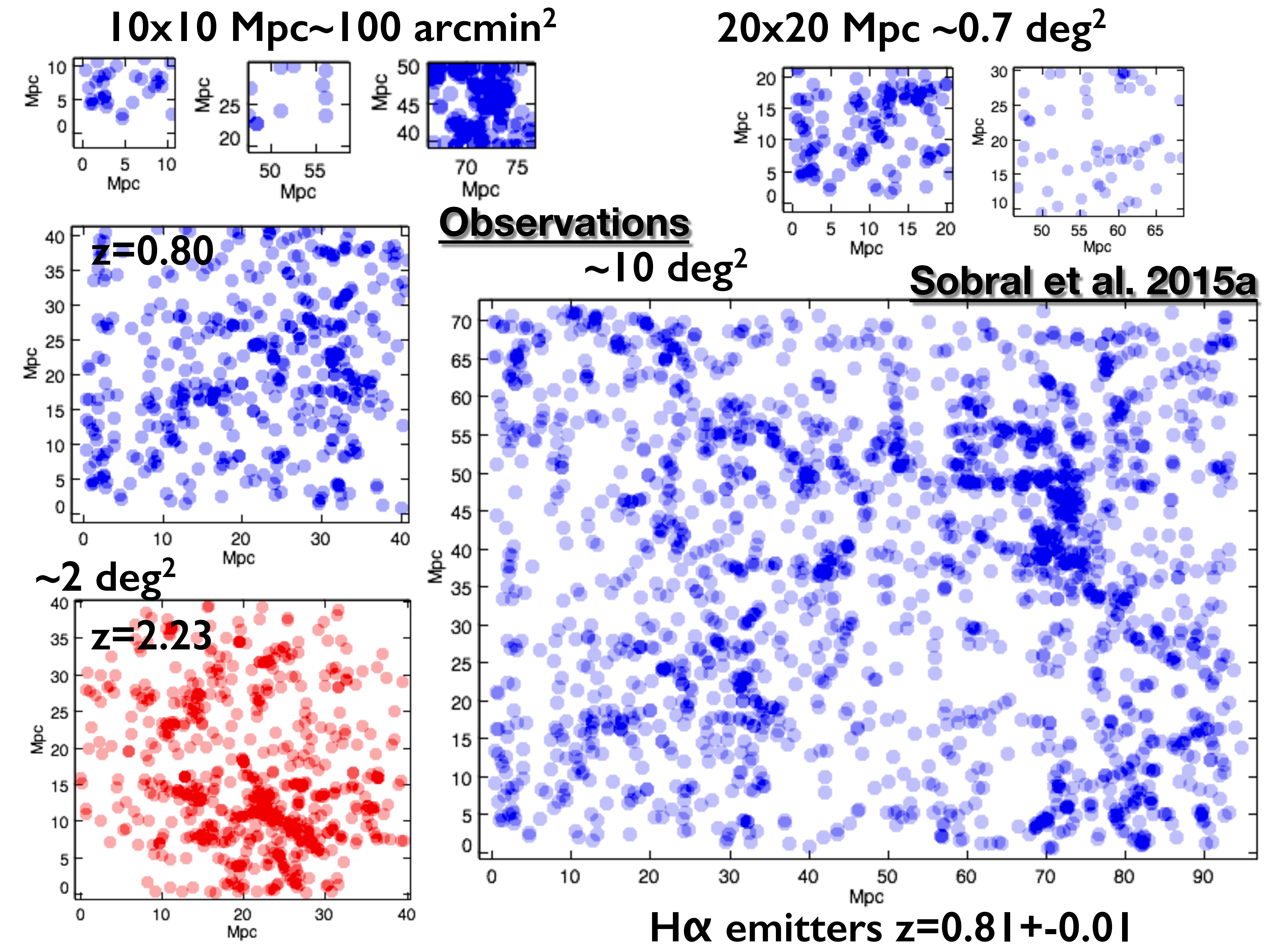
Evolution at all Luminosities (?)



Lyman-α Luminosity function at z=6.6

Surveys limited by cosmic variance (<1deg²)

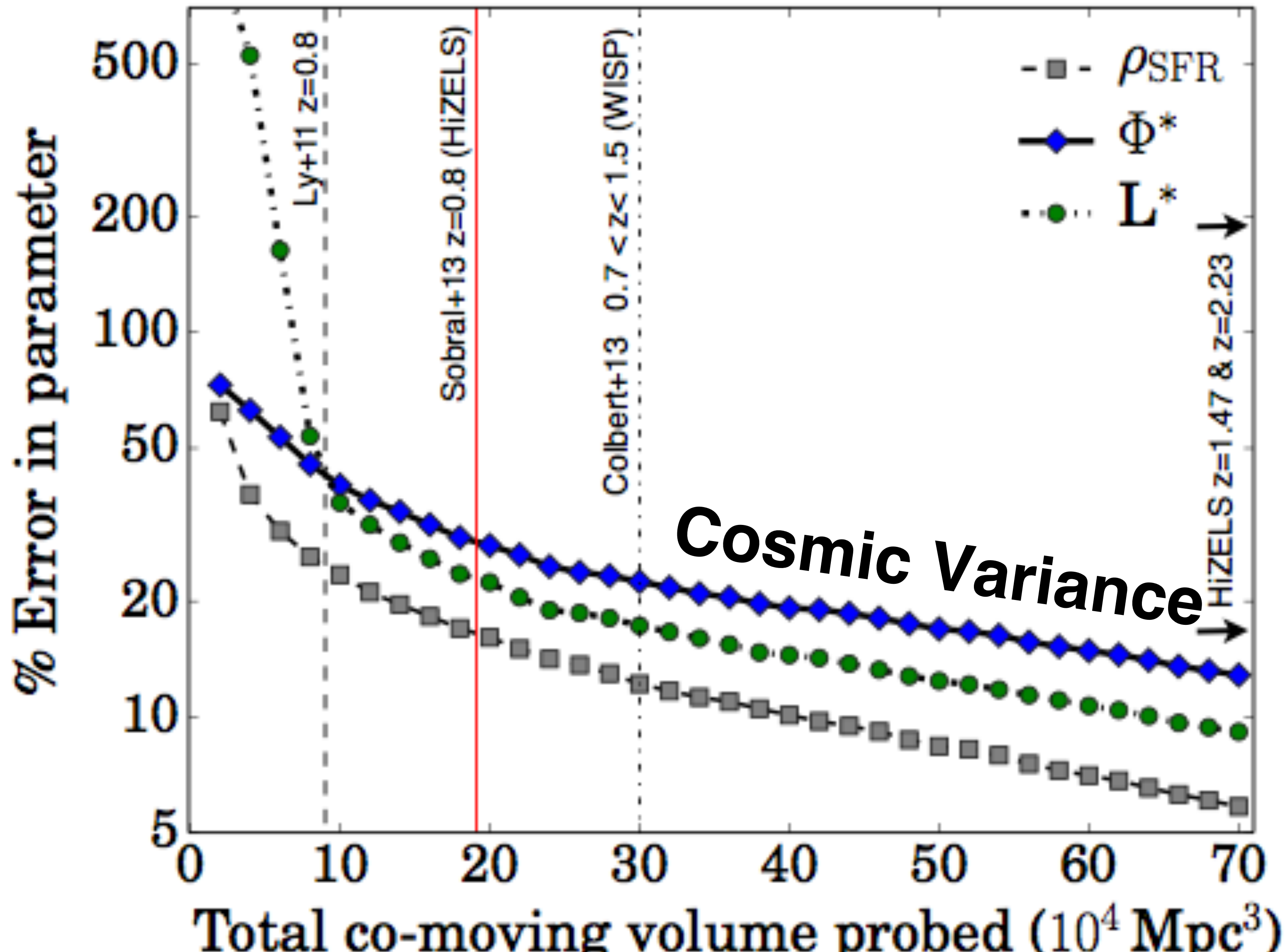



10x10 Mpc~100 arcmin²
20x20 Mpc ~0.7 deg²
Observations
~10 deg²
Sobral et al. 2015a
z=0.80
~2 deg²
z=2.23
Mpc
Hα emitters z=0.81+-0.01

Why we need large, multiple volumes!

<u>Sobral et al. 2015a</u>

Typical areas **1 deg^2** **10 deg^2**



<u>With *real* data</u>

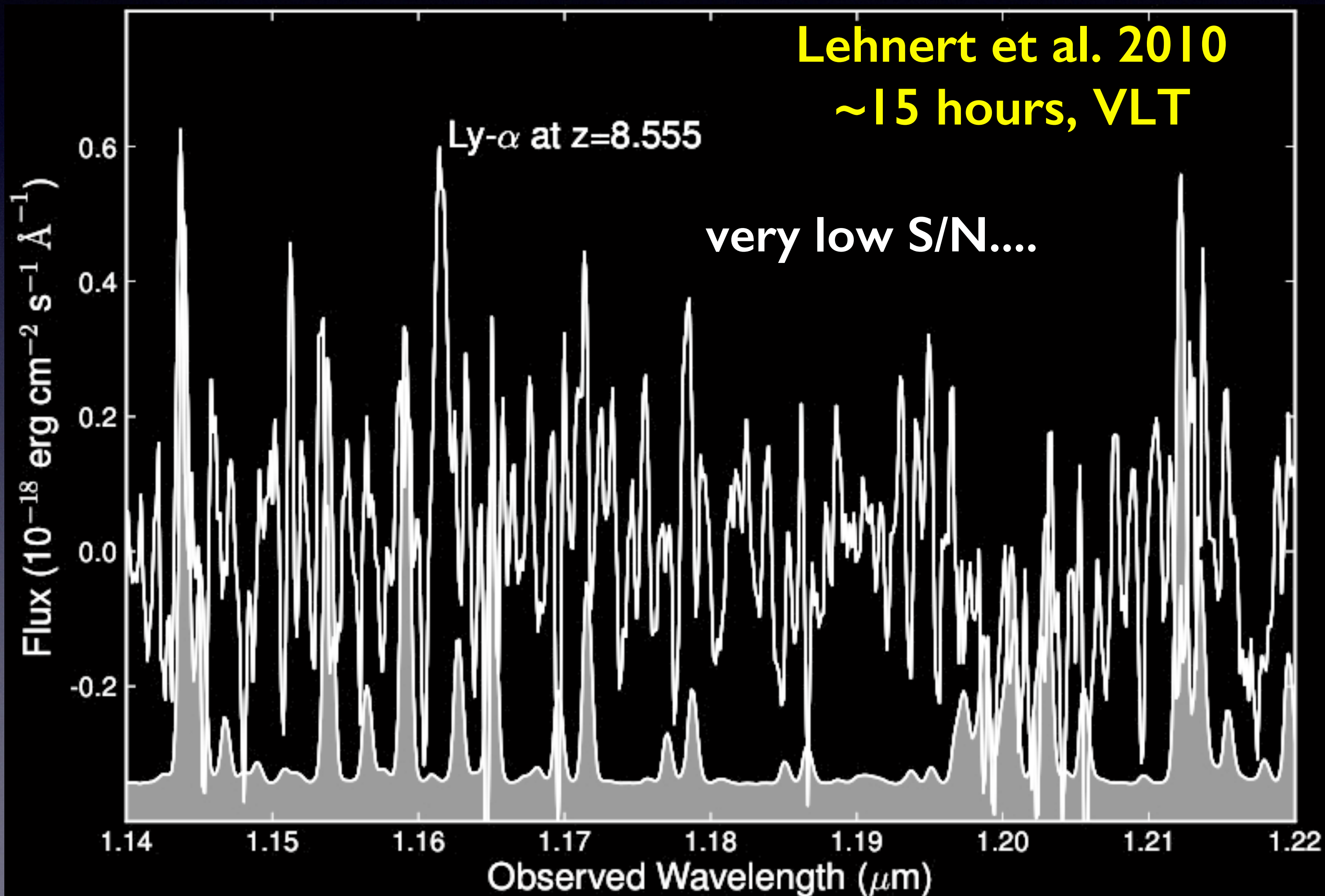
Errors < 20%

Key things to address

- Need much larger (and multiple!) volumes. Most luminous sources may be visible much earlier on (first ionised bubbles?)
- Need to spectroscopically confirm the results
- Find the most luminous sources: allowing for actual detailed studies to be conducted before JWST and/or E-ELT!

The big advantage for spectroscopic follow-up is that they will *not* look like this:

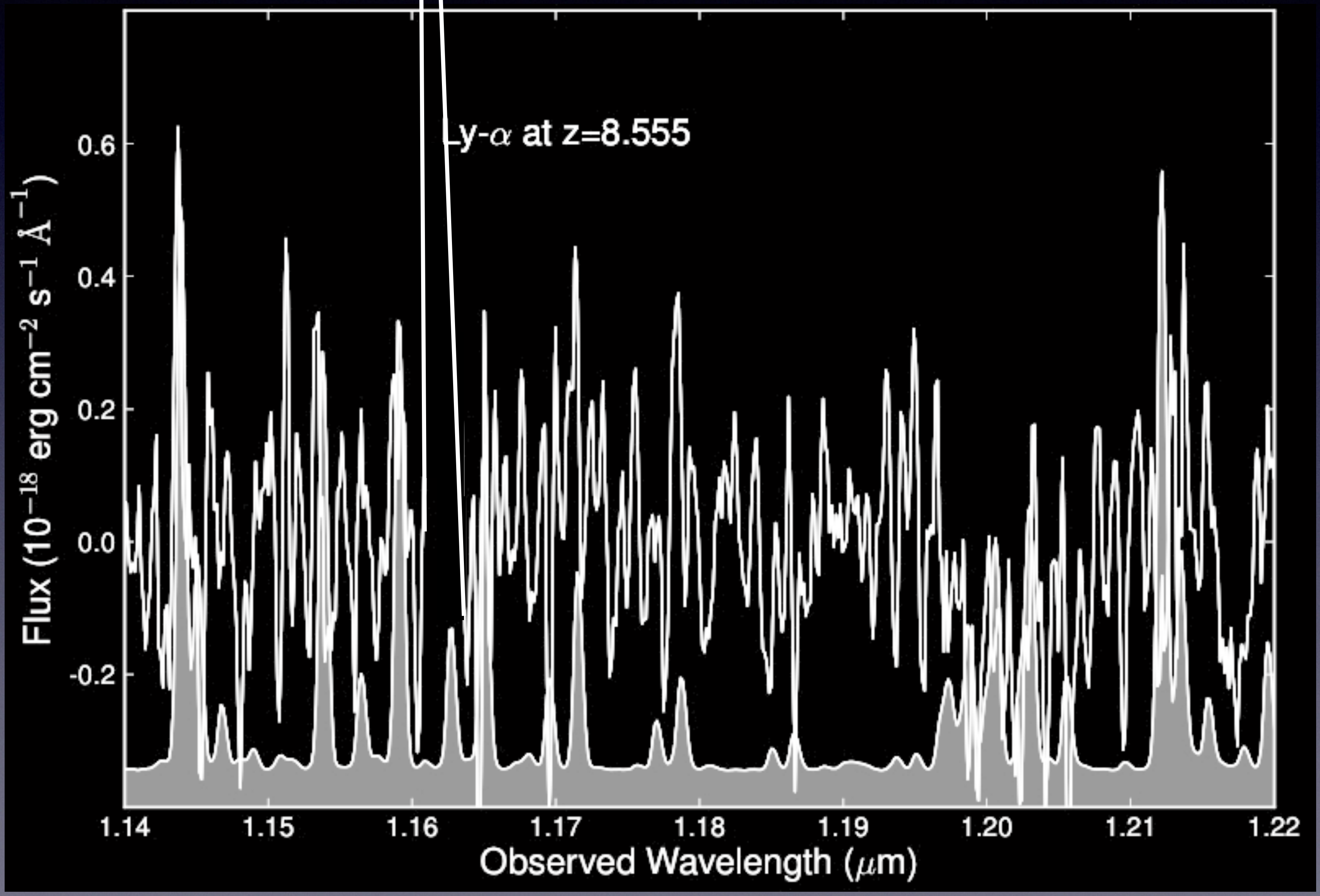
(see Bunker et al. 2013)



In ~ couple of hours

They will look like this!

See also: Oesch+2015



The widest survey ever undertaken: 5 deg^2 Lyα survey (z=6.6) in UDS, COSMOS and SA22

Subaru/Suprime-cam

NB921: Lyman-α at z=6.6

UDS, 0.9 deg^2, NB921<26

COSMOS, 0.9 deg^2, NB921<25.5

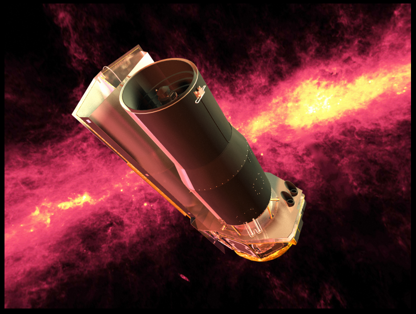
SA22-Deep, 0.3 deg^2, NB921<26
SA22-Wide, 2.7 deg^2, NB921<24.2

Surveys:

SDXF, UKIDSS-UDS, SpUDS, UDSz
COSMOS, UltraVISTA,
S-COSMOS, zCOSMOS

CFHTLS, UKIDSS-DXS




Matthee, Sobral et al. 2015, MNRAS (arXiv:1502.07355)

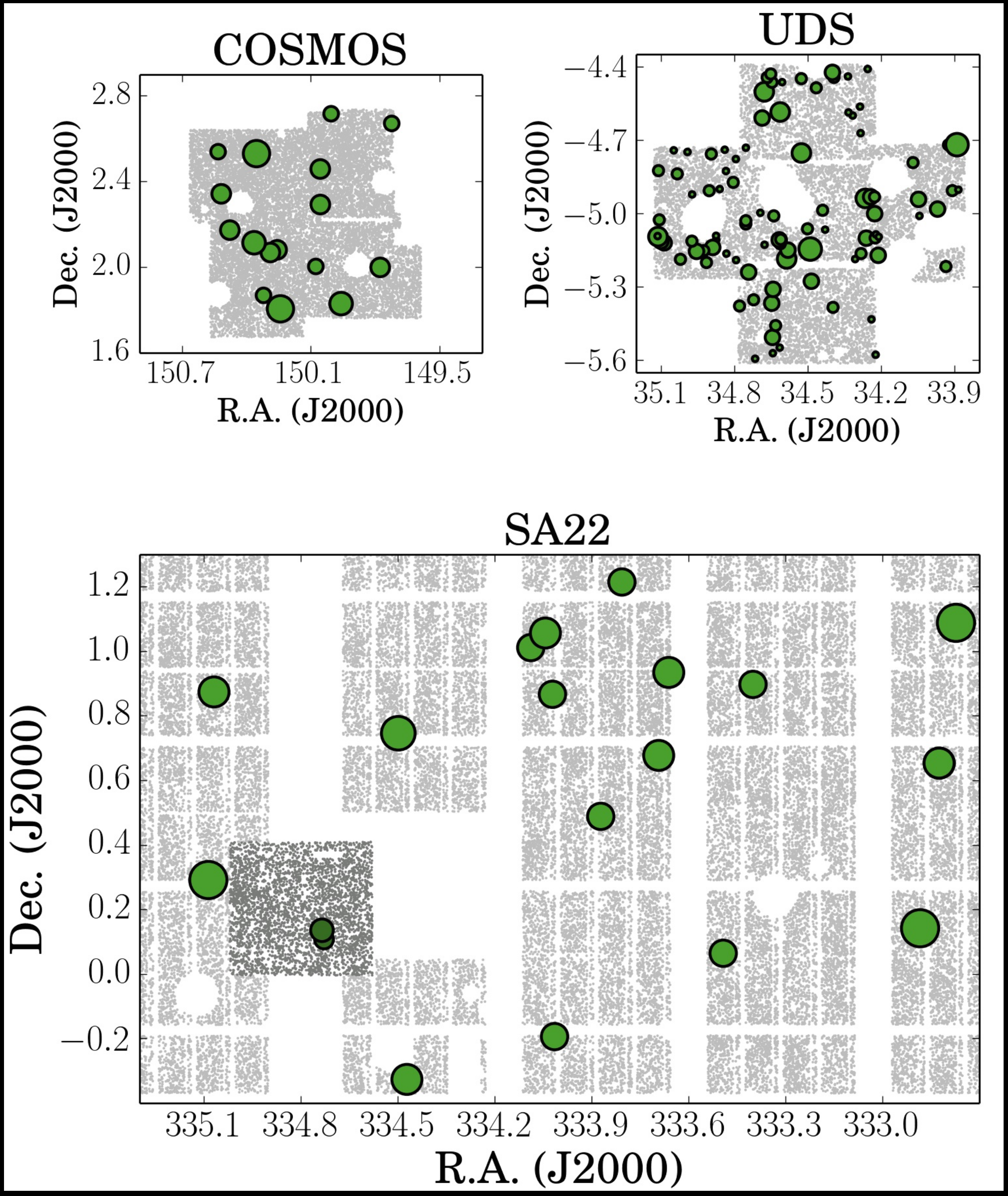
Results:

99 LAEs in UDS

15 LAEs in COSMOS

2 LAEs in SA22-Deep

18 LAEs in SA22-Wide



<u>Results</u>:

99 LAEs in UDS
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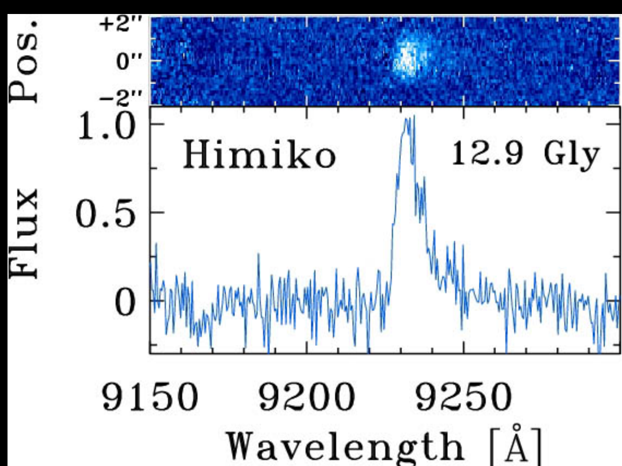
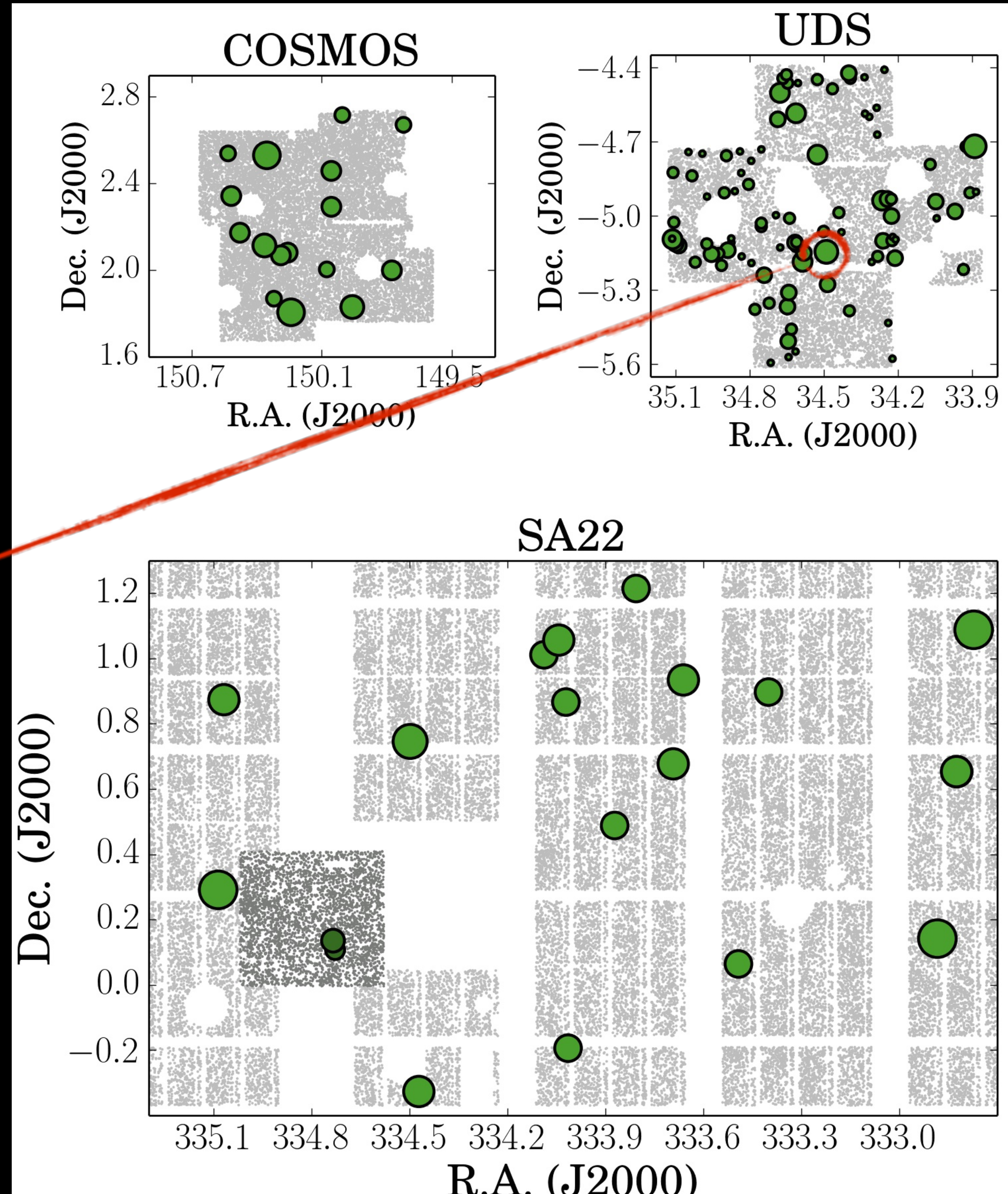




Ouchi et al. 2009, 2013

Results:

99 LAEs in UDS

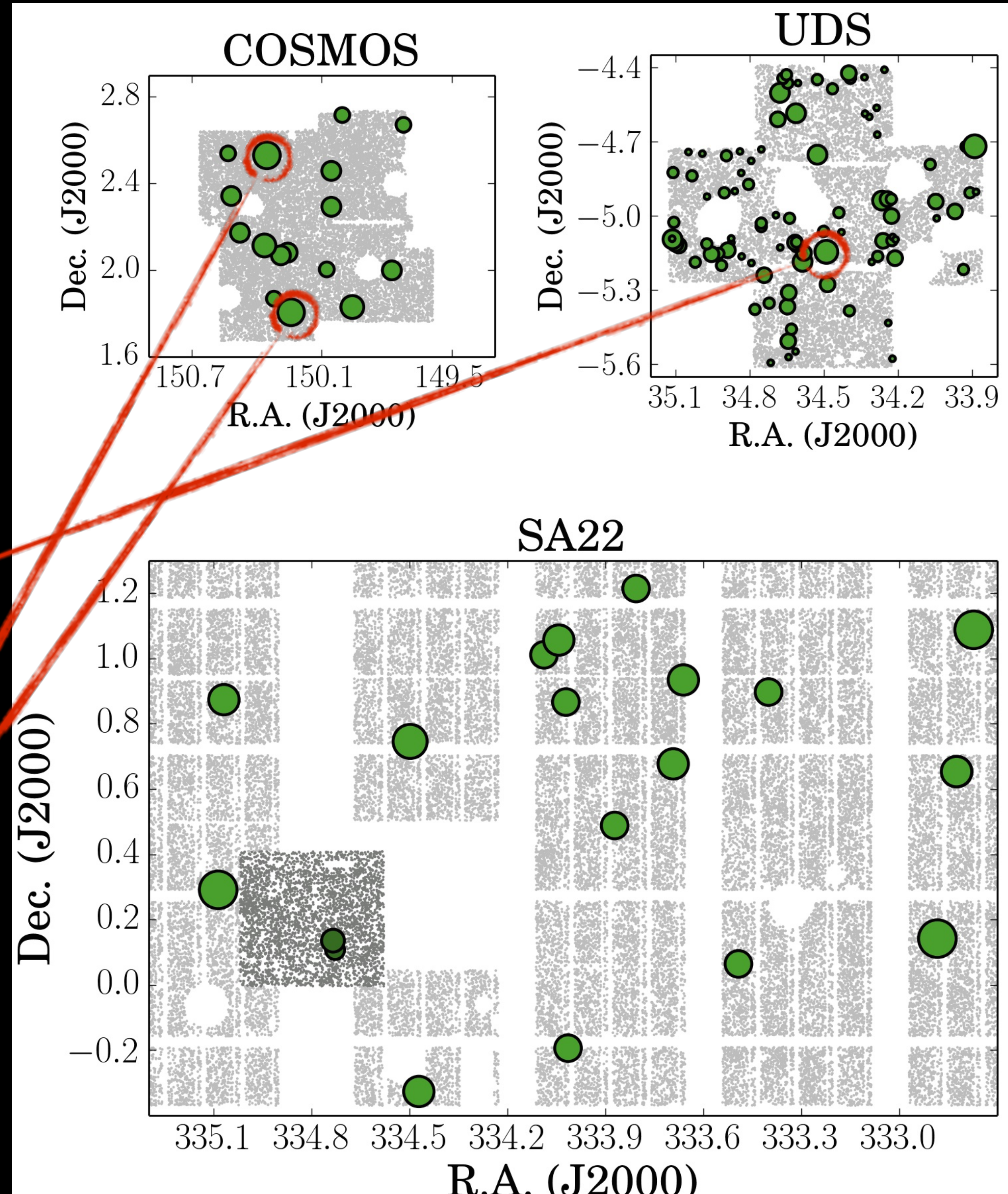
15 LAEs in COSMOS

2 LAEs in SA22-Deep

18 LAEs in SA22-Wide

"Himiko"

Even brighter!



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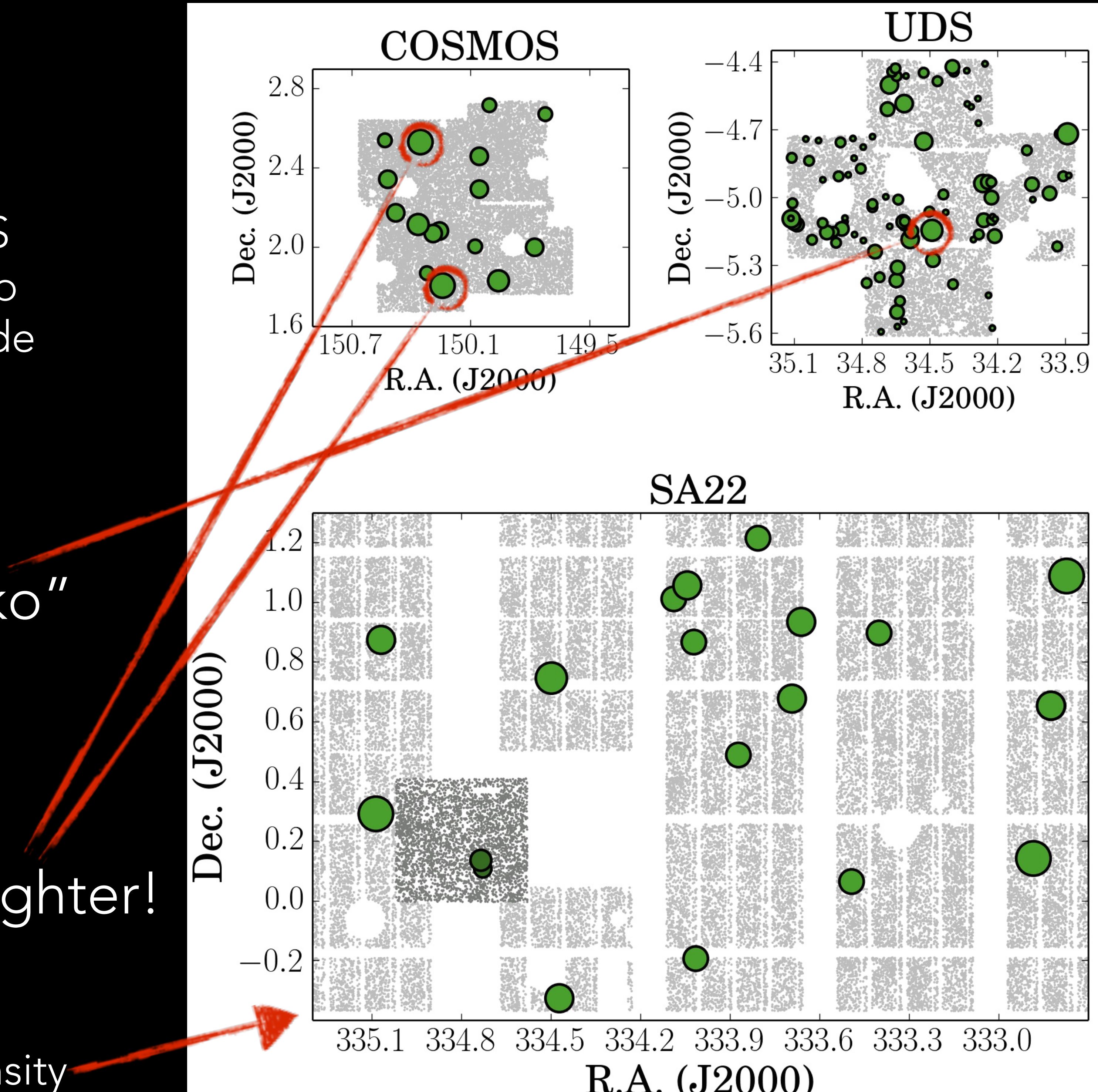
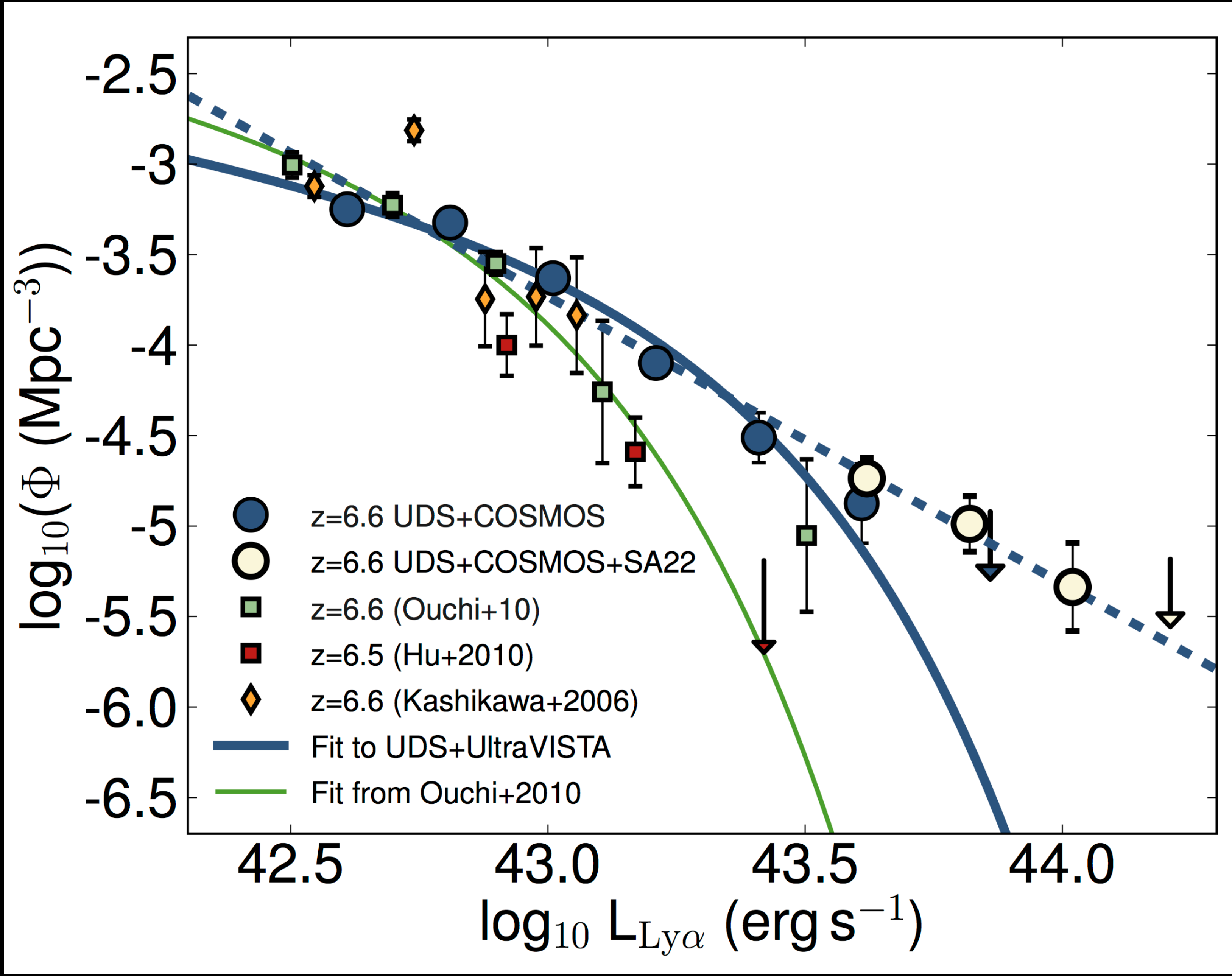


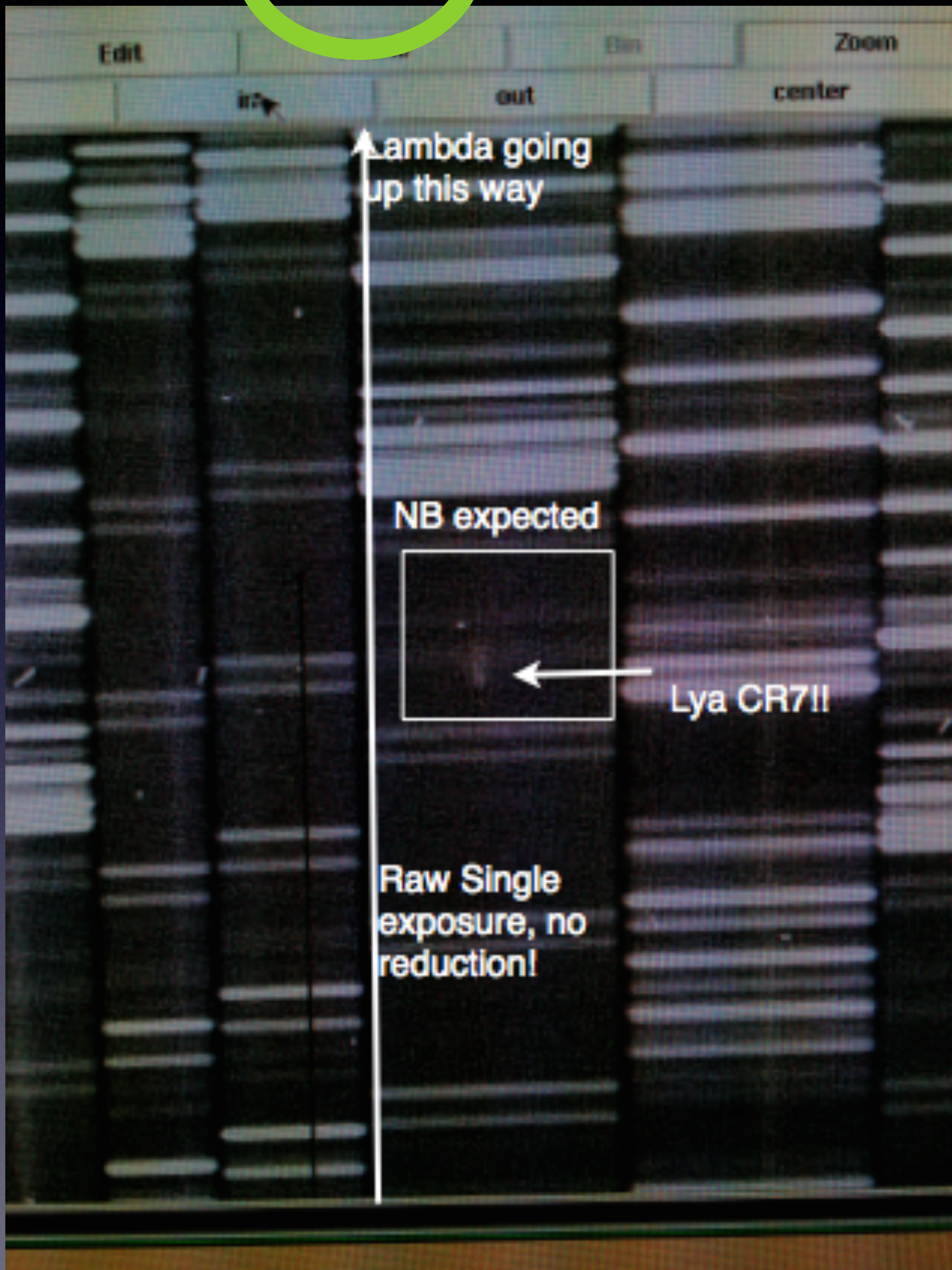
Lyman-α Luminosity function at z=6.6



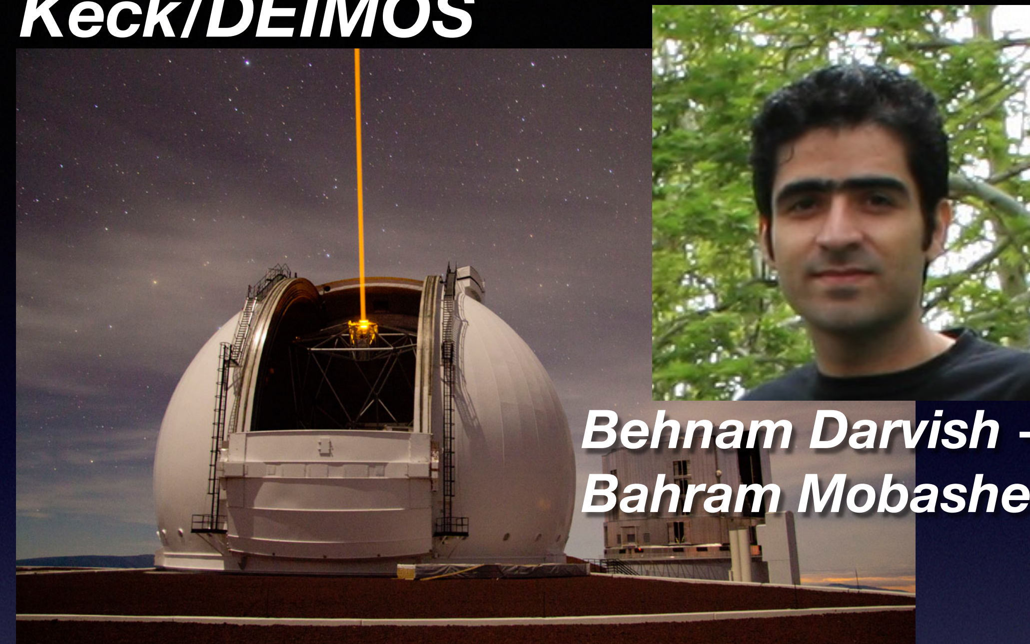
see also: Bowler et al. 2012, 2014

Matthee, Sobral et al. 2015, MNRAS (arXiv:1502.07355)

15 min z=6.6



Spectroscopic confirmation with Keck/DEIMOS



Behnam Darvish + Bahram Mobasher

Spectroscopic confirmation with VLT/X-SHOOTER + FORS2

DDT time, PI: Sobral

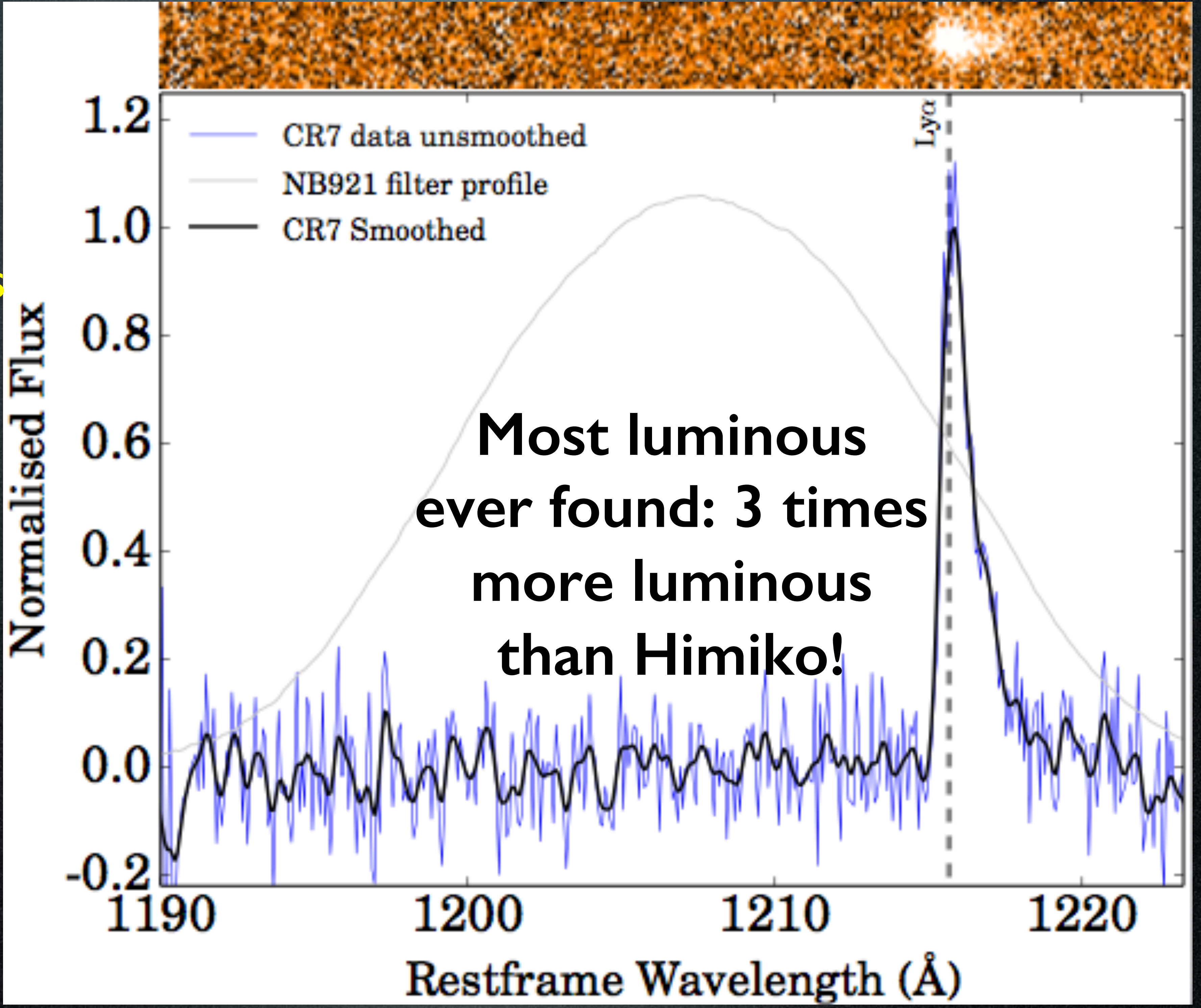
Lyα

Keck/DEIMOS

1 hour!

z=6.6

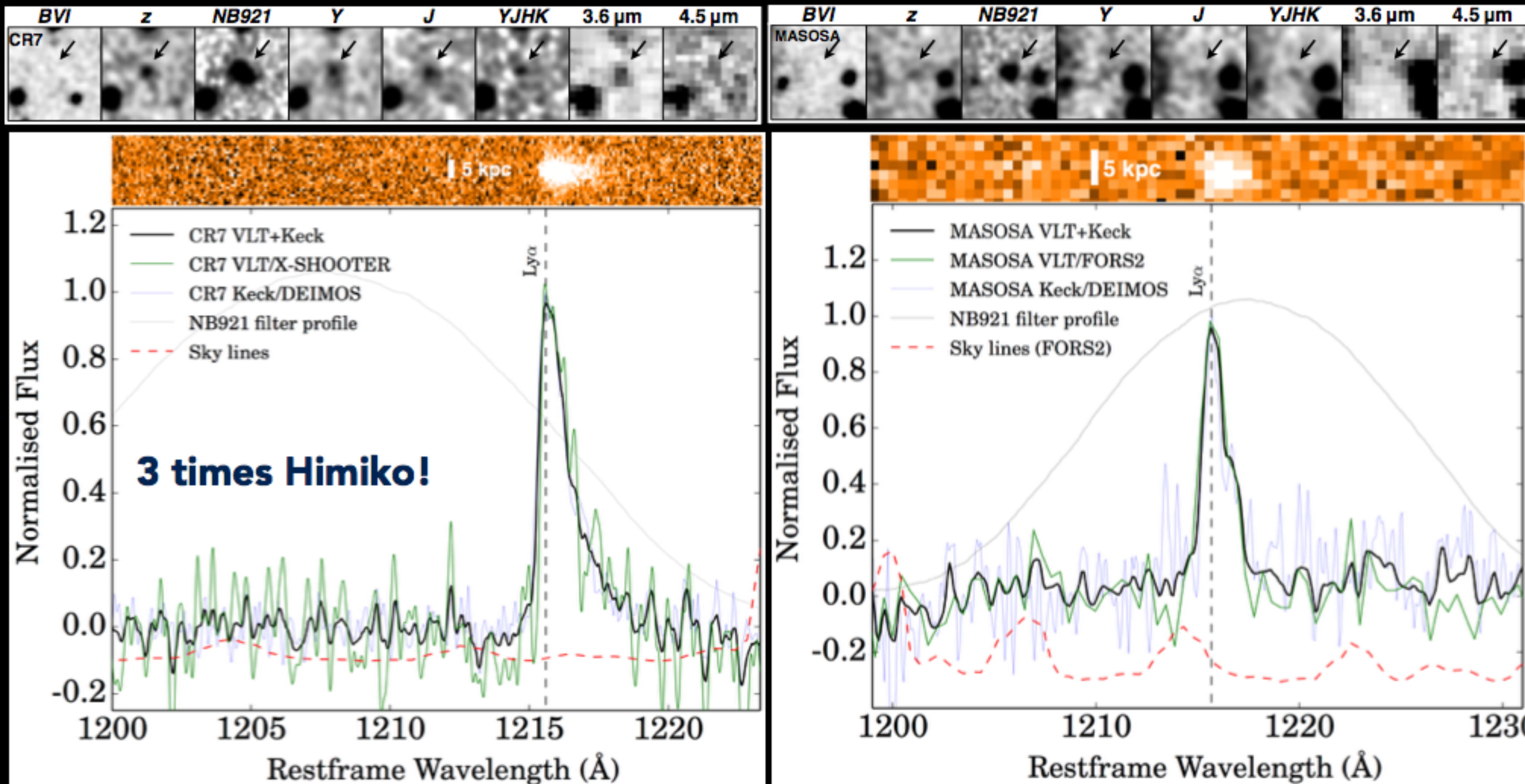
L~10^{44} erg/s/cm^2



No evidence for AGN

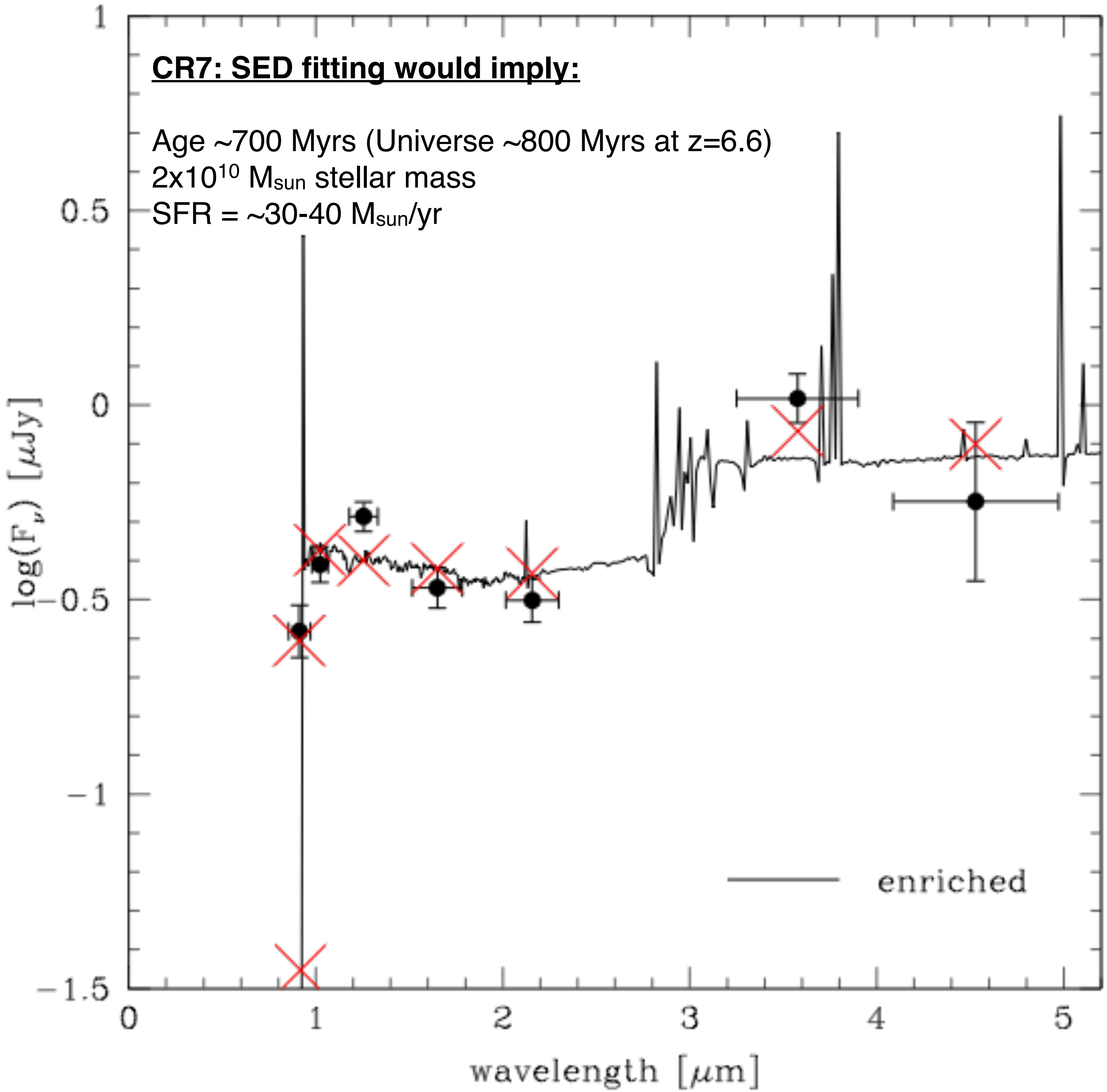
Sobral et al. 2015c.

`COSMOS REDSHIFT 7' (CR7) AND `MASOSA' THE BRIGHTEST Z=6.6 LAES

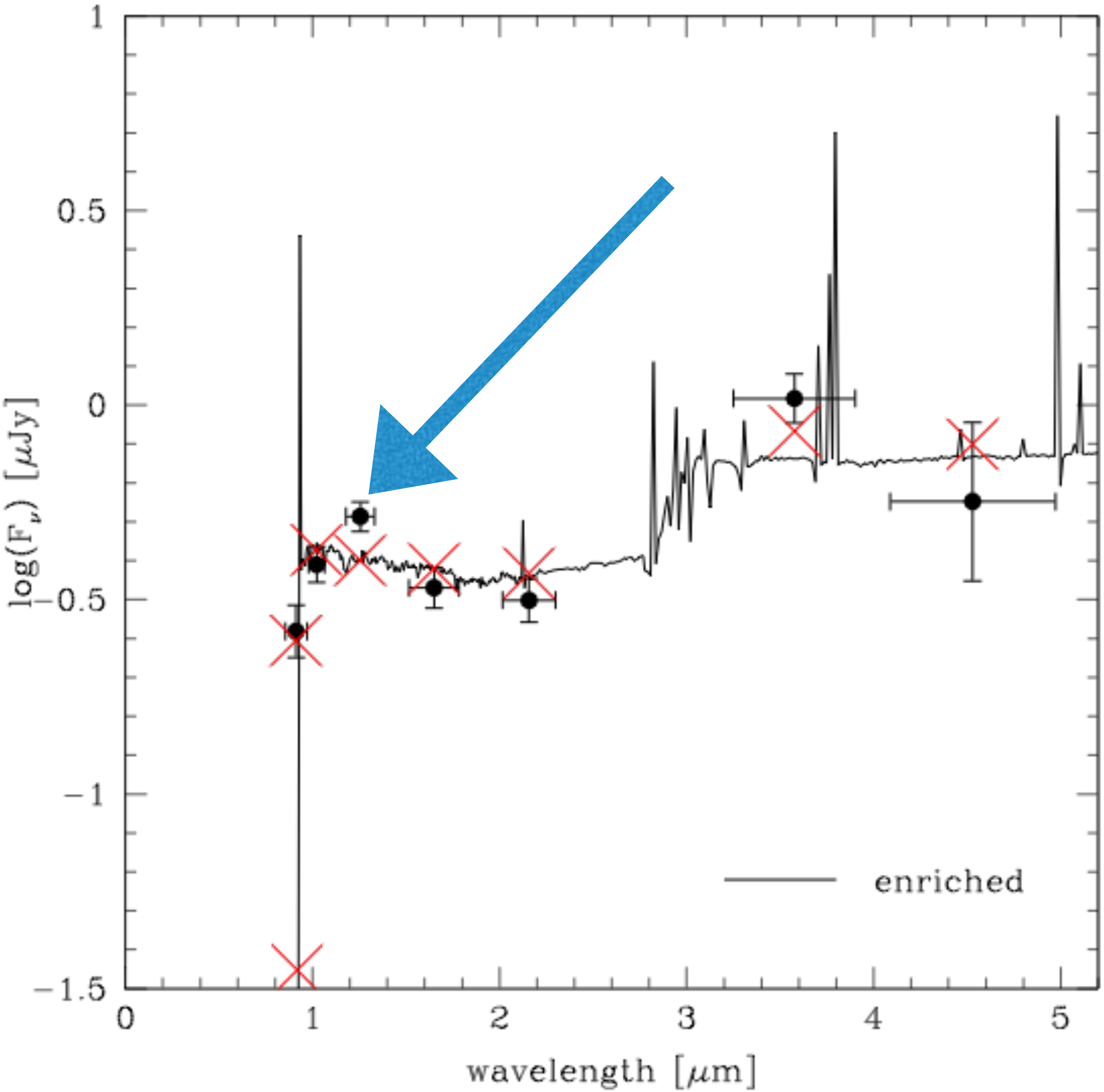


DDT: VLT/X-Shooter + Keck/DEIMOS **(~3.8 hours)** DDT: VLT/FORS2 + Keck/DEIMOS **(~2.4 hours)**

Sobral, Matthee et al. 2015 ApJ in press (arXiv: 1504.01734)



Sobral, Matthee, Darvish et al. 2015



Sobral, Matthee, Darvish et al. 2015

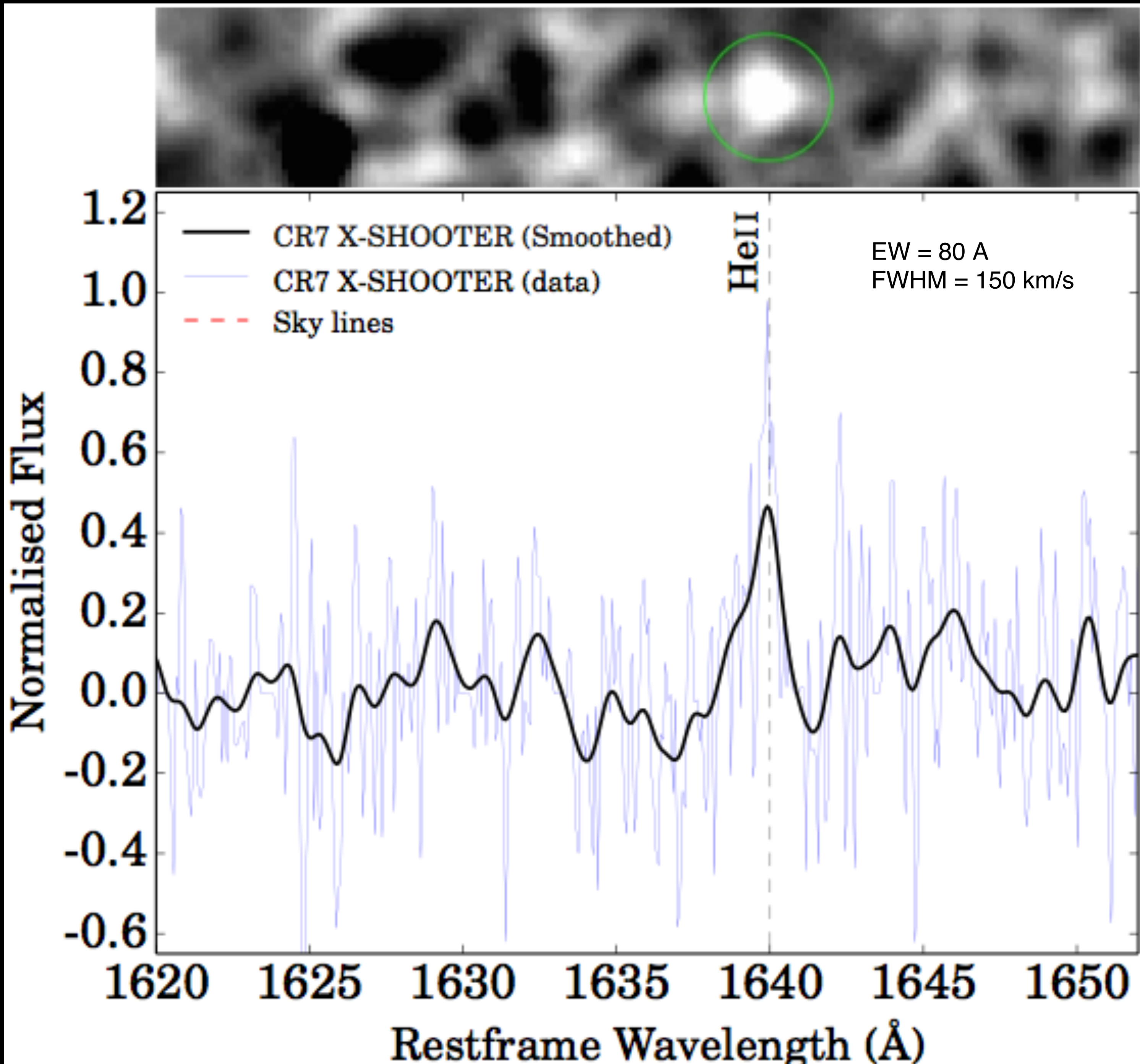
CR7: X-SHOOTER: 2 hours

Anything interesting to explain J excess?

The J-band excess could be due to CIV1549, HeII1640, OIII]1661, OIII]1666 or NIII]1750

From the Xshooter near-IR spectra ONLY HeII 1640 is detected. None of the other lines were found to be significant

CR7: X-SHOOTER: 2 hours   HeII 1640!   6 sigma!

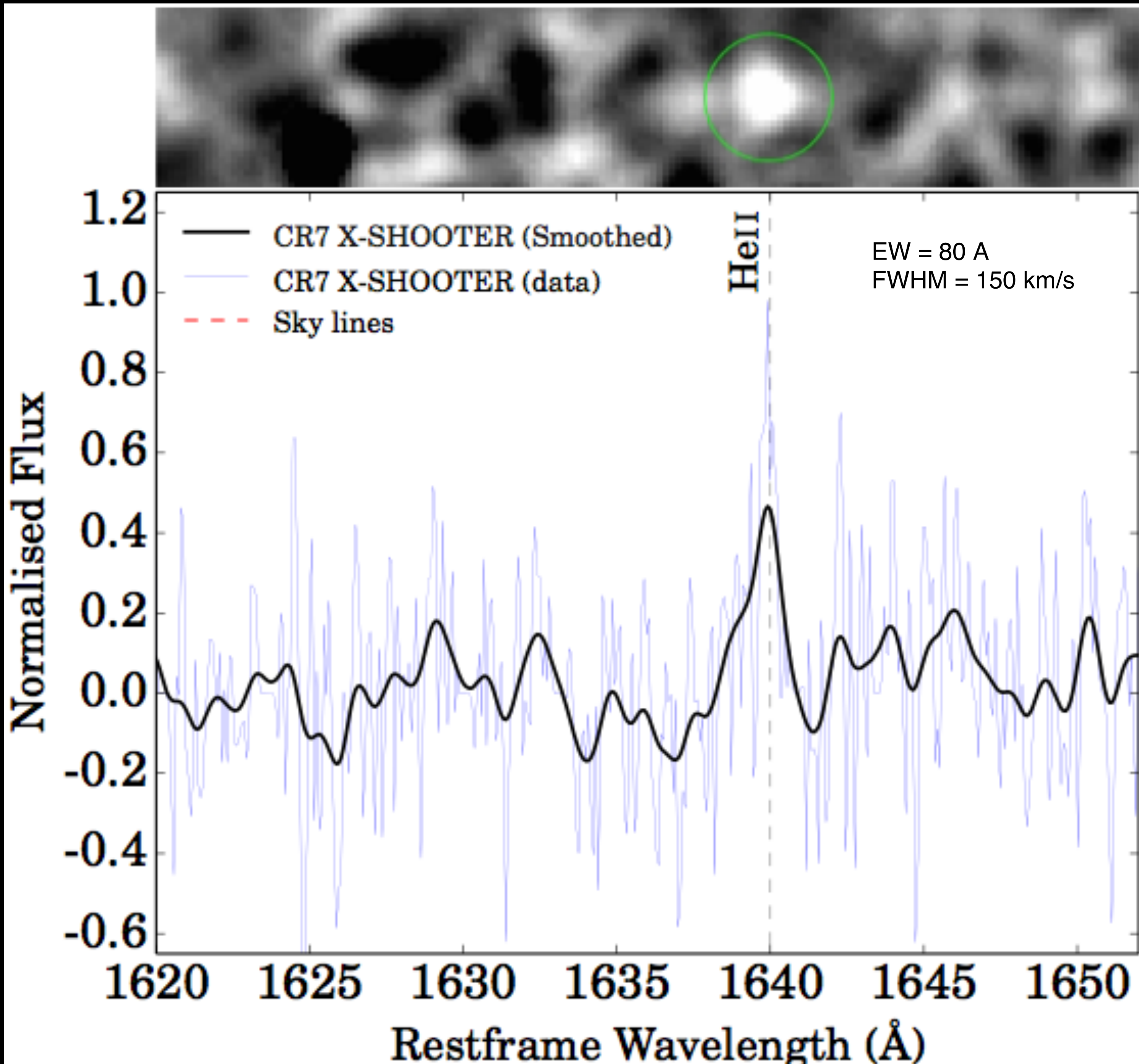


FWHM= 130 km/s

HeII/Lya = 0.27+-0.09

Sobral, Matthee, Darvish et al. 2015

CR7: X-SHOOTER: 2 hours HeII 1640! 6 sigma!



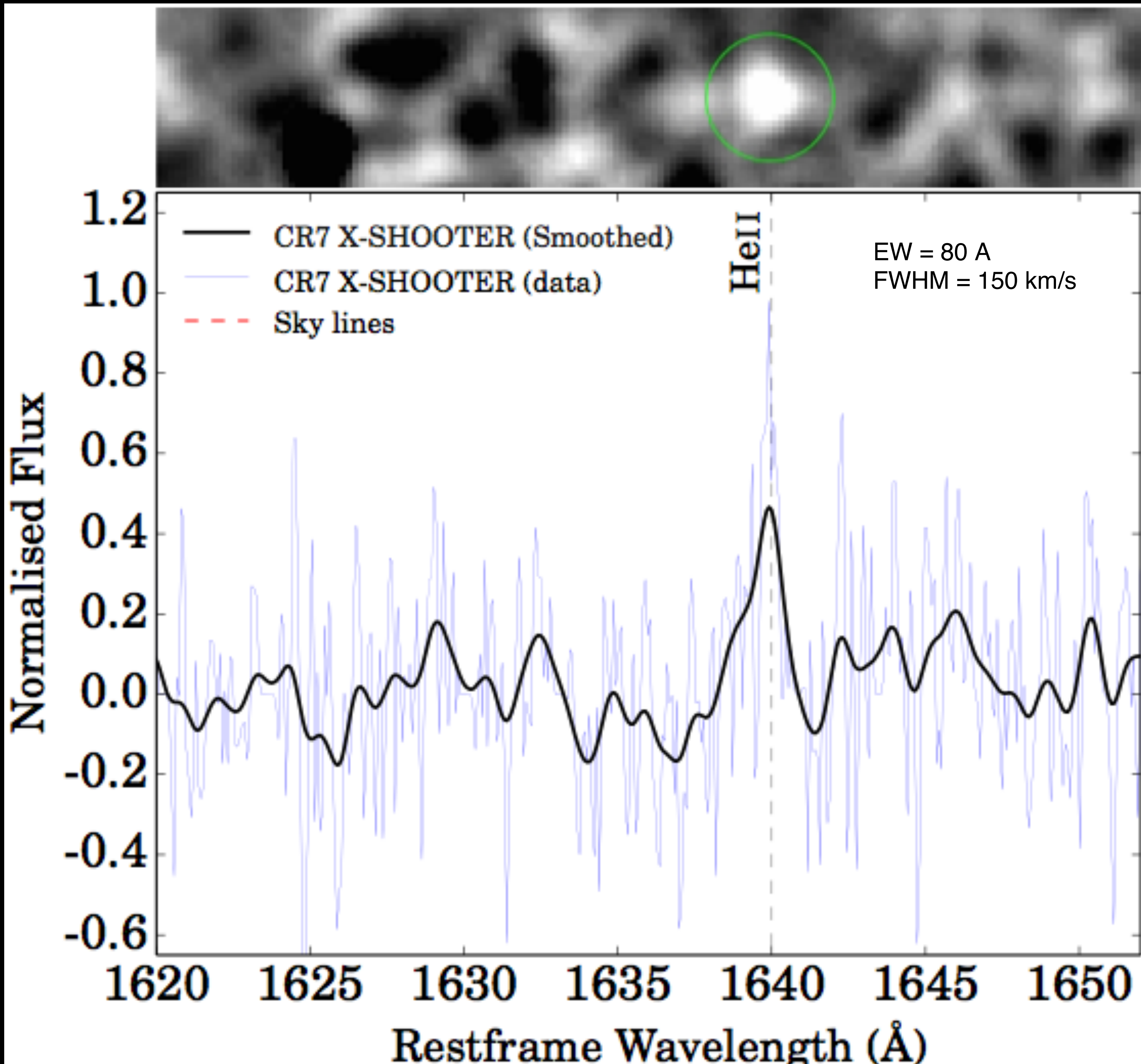
FWHM= 130 km/s

HeII/Lya = 0.27+-0.09

>>> DDT time on SINFONI/VLT to fully confirm

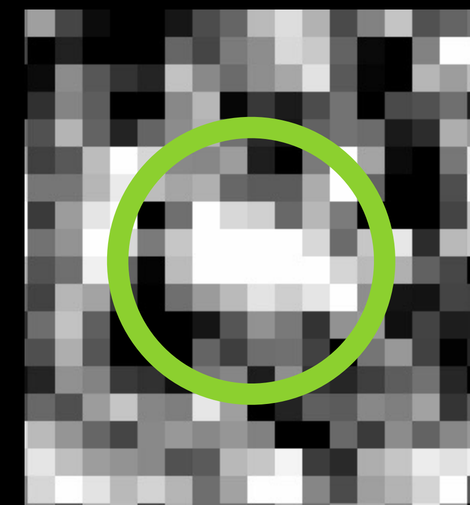
Sobral, Matthee, Darvish et al. 2015

CR7: X-SHOOTER: 2 hours



SINFONI: 3 hours

HeII 1640A in 2D!



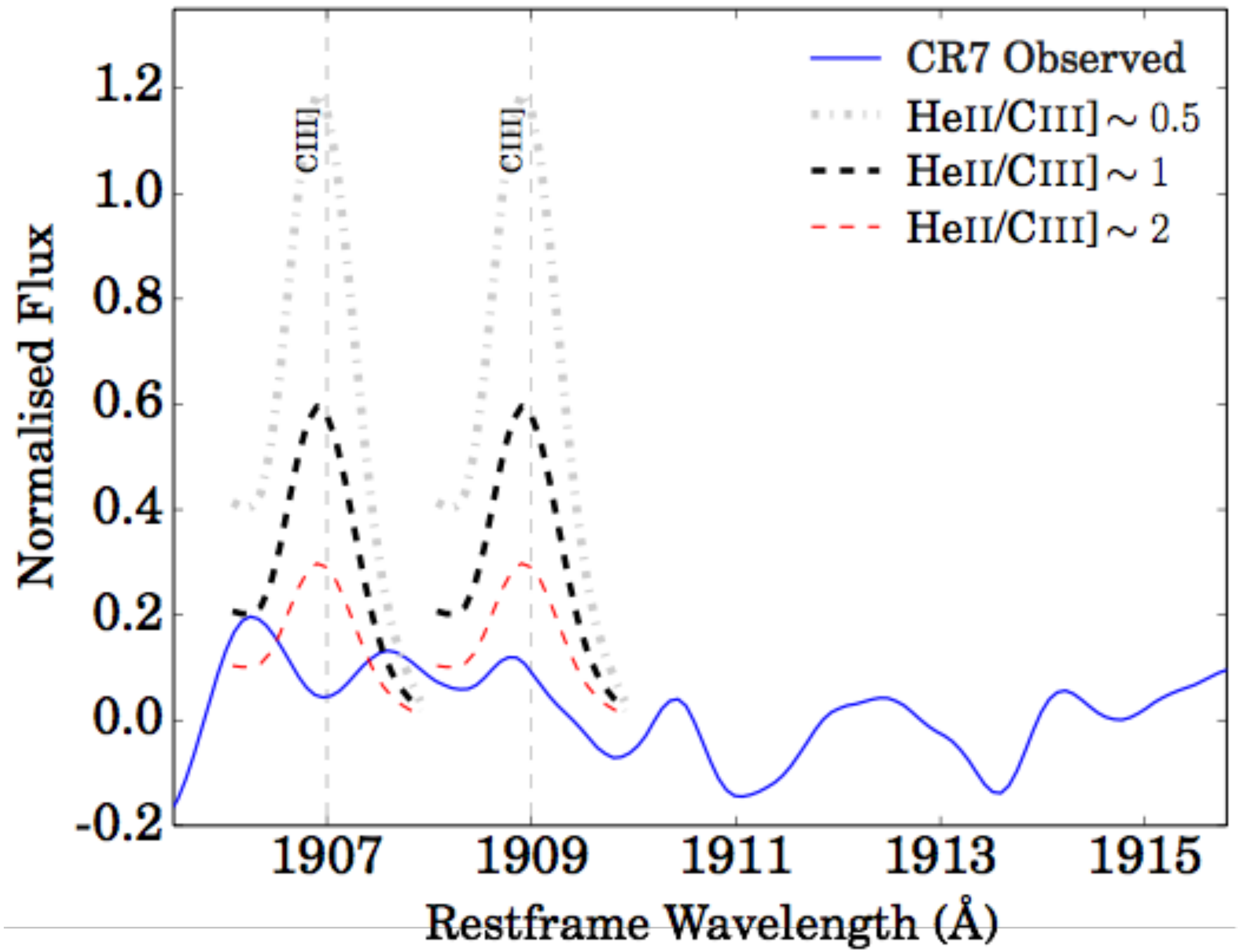
HeII EW_0>70 A

HeII $FWHM_0$= 130 km/s

HeII/Lya ~ 0.2

Sobral, Matthee, Darvish et al. 2015

Apart from bright narrow Lyα and HeII1640: <u>no other emission lines detected</u>



HeII/Lyα~0.2

E.g.:
No CIII]1908
No OIII]1663
No NV

Lyα/NV >70
HeII/OIII]>3
HeII/CIII]>2.5

<u>Sobral, Matthee, Darvish et al. 2015</u>

This is what we have:

Measurement[a]	CR7	MASOSA	Himiko
z_{spec} Lyα	$6.604^{+0.001}_{-0.003}$	6.541 ± 0.001	6.54
β UV slope	-2.3 ± 0.08	—	-2.0 ± 0.57
Lyα (FWHM, km s^{-1})	266 ± 15	386 ± 30	251 ± 21
Lyα ($EW_{0,obs,Y}$[b], Å)	211 ± 20	> 206	78 ± 8
Lyα ($EW_{0,obs,spec}$, Å)	> 230	> 200	—
Lyα ($Log_{10}L$, erg s^{-1})	43.93 ± 0.05	43.38 ± 0.06	43.40 ± 0.07[c]
Lyα/NV	> 70	—	—
HeII/Lyα	0.27 ± 0.09	—	—
HeII (EW_0, Å)	80 ± 20 (> 20)	—	—
HeII (FWHM, km s^{-1})	130 ± 30	—	—
HeII/OIII]1663	> 3	—	—
HeII/CIII]1908	> 2.5	—	—
Photometry	**CR7**	**MASOSA**	**Himiko**
BVI	> 28	> 28	> 28.7[1]
z	25.35 ± 0.20	26.28 ± 0.37	25.86 ± 0.20[d]
NB921 2" aperture	23.70 ± 0.04	23.84 ± 0.04	23.95 ± 0.02[e]
NB921 MAG-AUTO	23.24 ± 0.03	23.81 ± 0.03	23.55 ± 0.05[d]
Y	24.92 ± 0.13	> 26.35	25.0 ± 0.35[f]
J	24.62 ± 0.10	> 26.15	25.03 ± 0.25[d]
H	25.08 ± 0.14	> 25.85	25.5 ± 0.35[f]
K	25.15 ± 0.15	> 25.65	24.77 ± 0.29[d]
3.6μm	23.86 ± 0.17	> 25.6	23.69 ± 0.09[d]
4.5μm	24.52 ± 0.61	> 25.1	24.28 ± 0.19[d]

Lyα EW>230 A

HeII EW =80 A

HeII/Lyα~0.2

No lines except Lyα and HeII

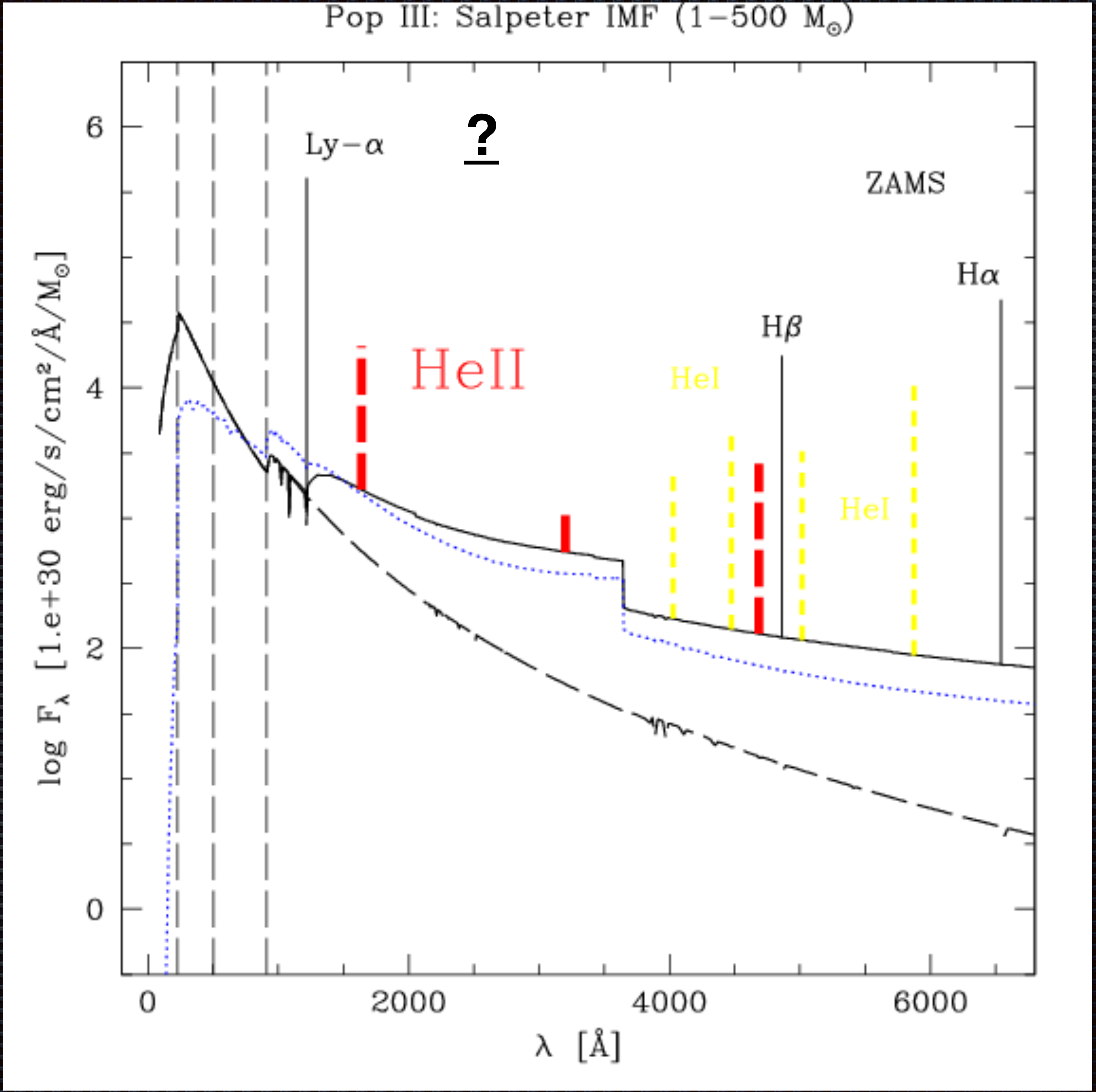
Narrow Lyα and narrow HeII

"Talks" like it

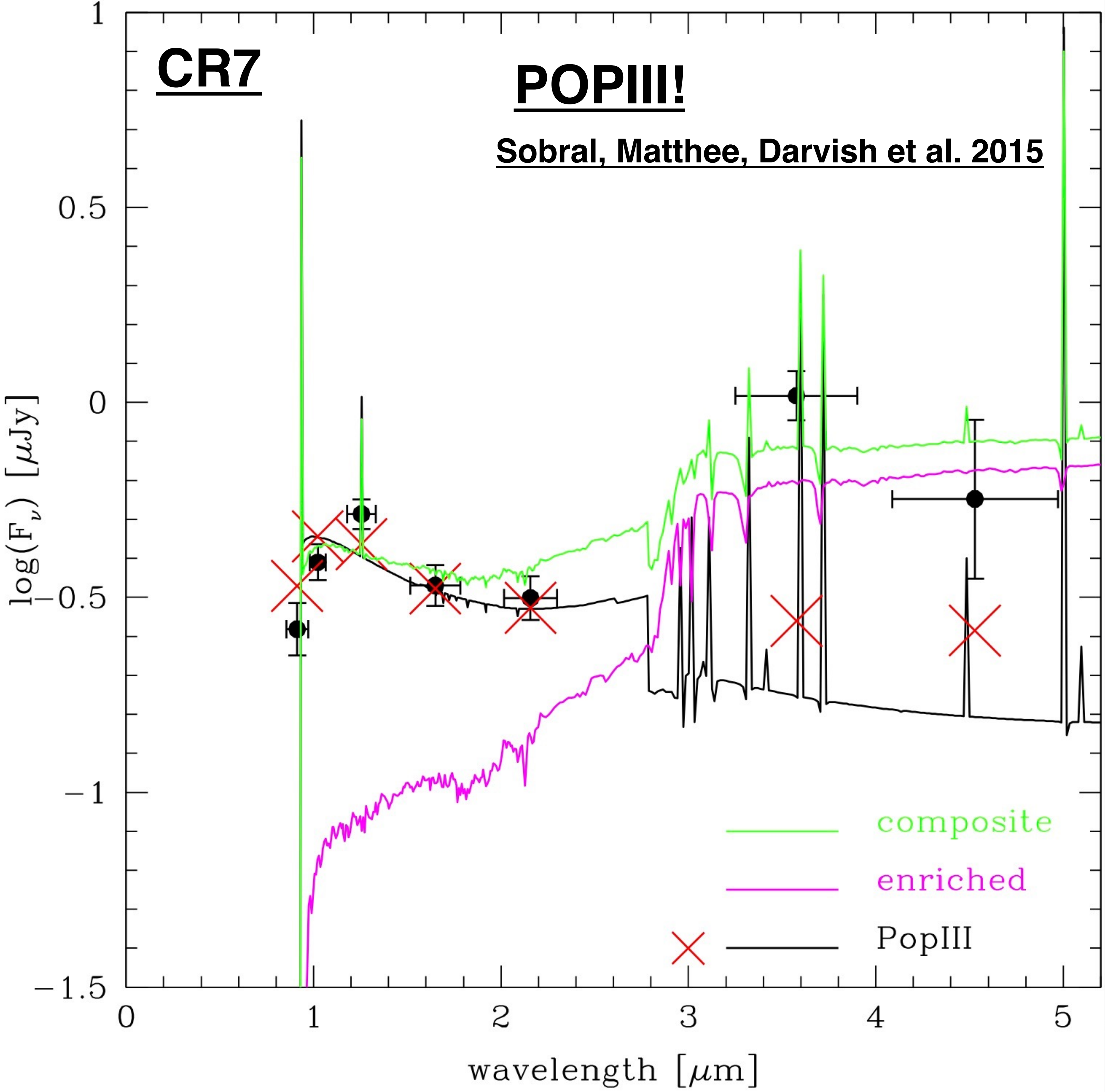
"Looks" like it

"Moves" like it

"Smells" like it

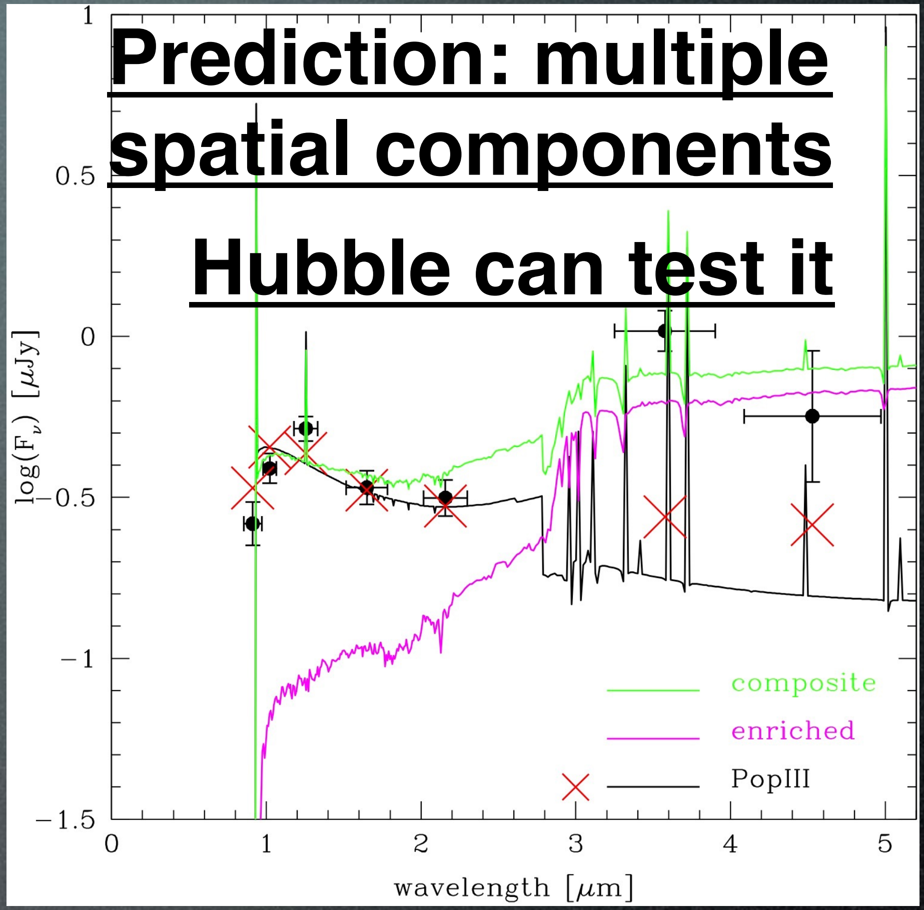


Pop III: Salpeter IMF (1−500 M☉)
Ly−α
?
ZAMS
Hα
Hβ
HeII
HeI
HeI
log F_λ [1.e+30 erg/s/cm²/Å/M☉]
λ [Å]
0
2
4
6
0
2000
4000
6000


CR7
POPIII!
Sobral, Matthee, Darvish et al. 2015
log(F_ν) [μJy]
wavelength [μm]
composite
enriched
PopIII
1
0.5
0
−0.5
−1
−1.5
0
1
2
3
4
5

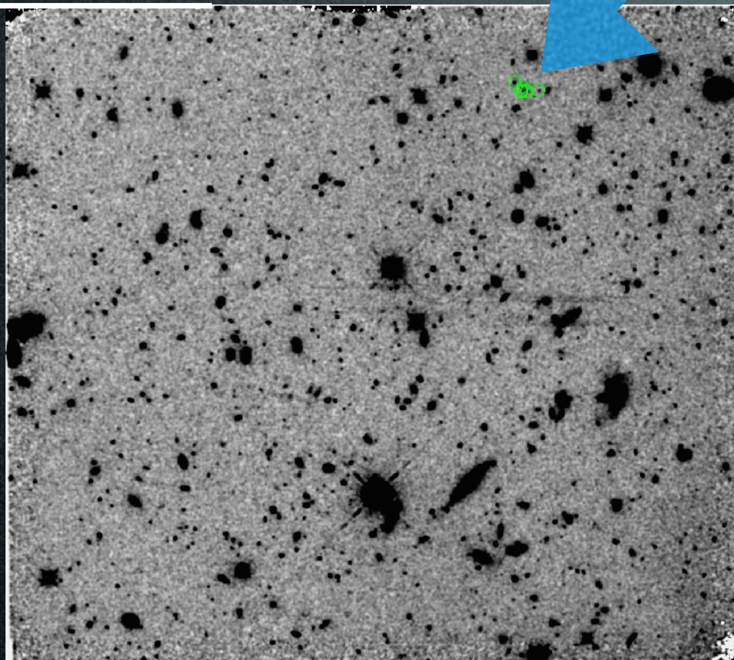
Prediction: multiple spatial components

Hubble can test it

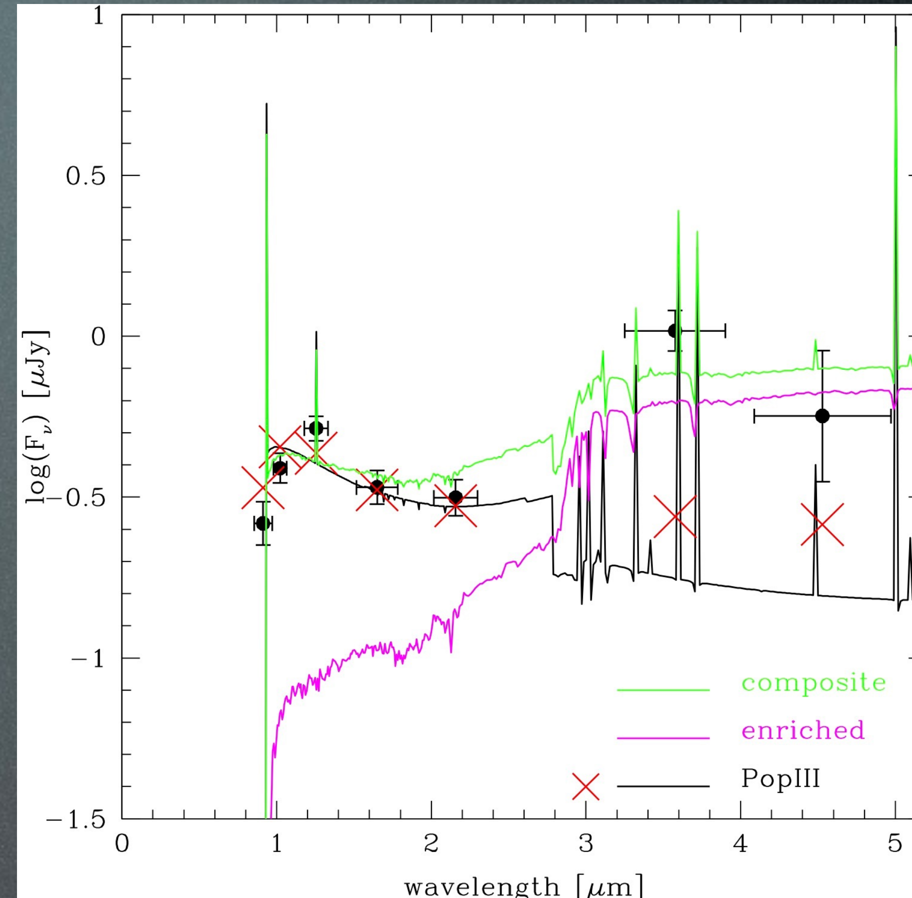


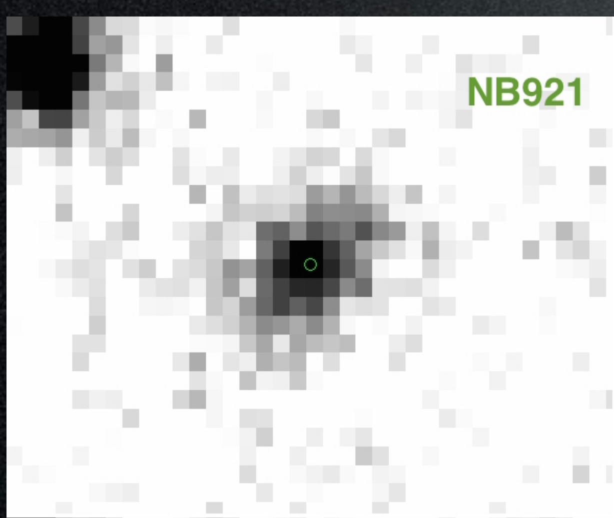
Ok… Need WFC3 observations to spatially resolve the image

WFC3!



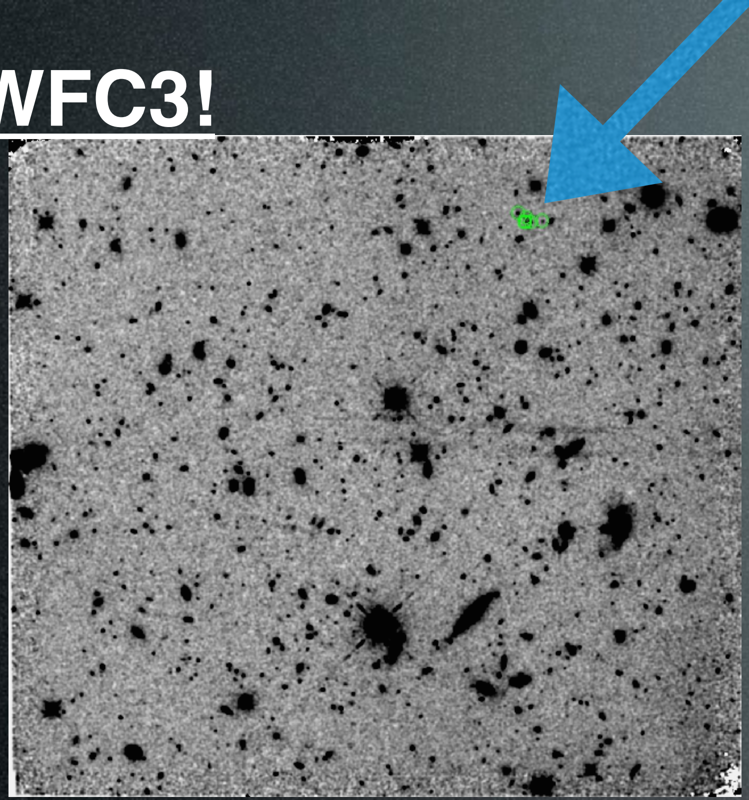
Actually… in the field of view of another target!





Make your bet: Multiple component (s): right or wrong?

WFC3!



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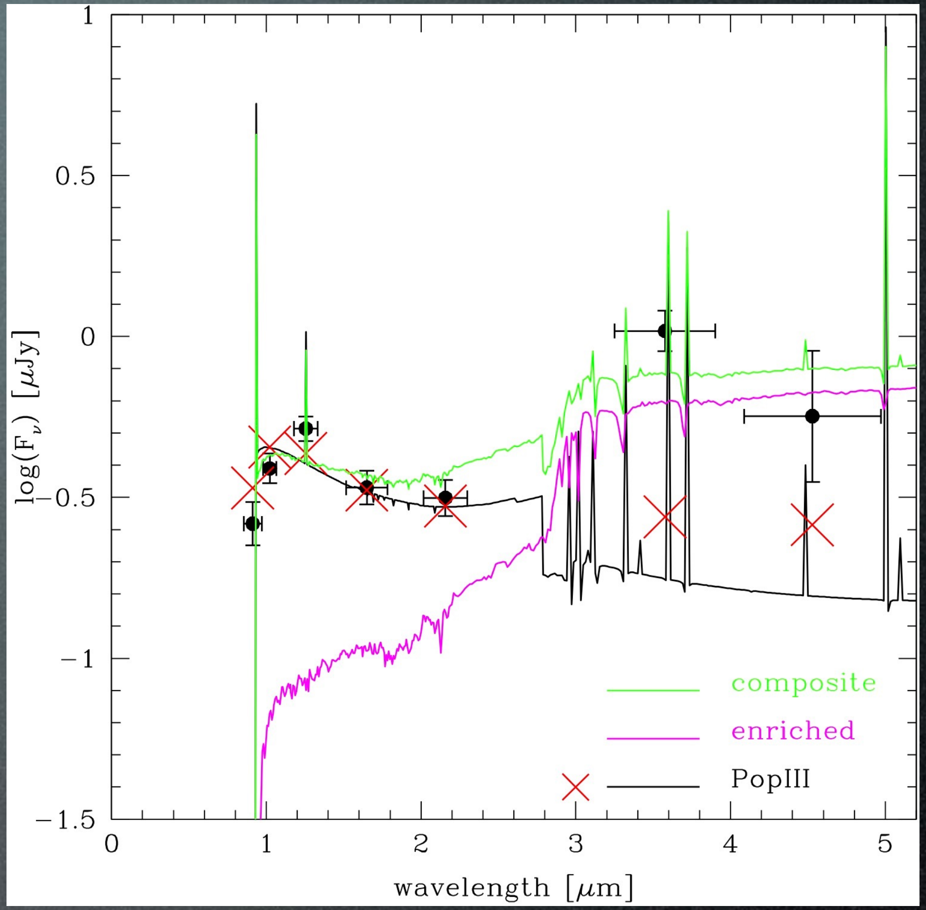
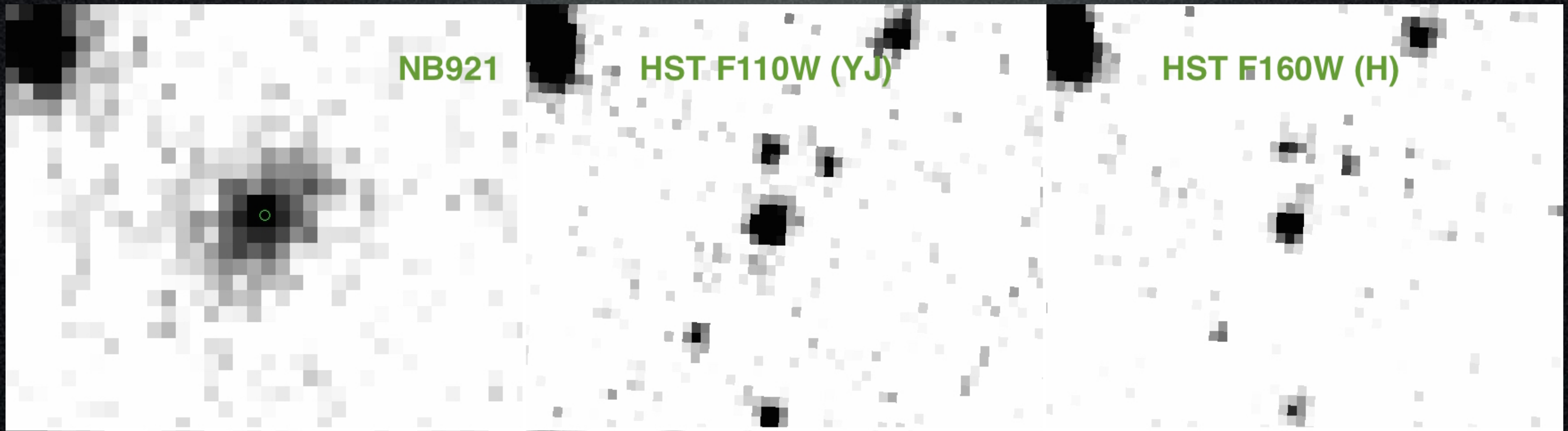
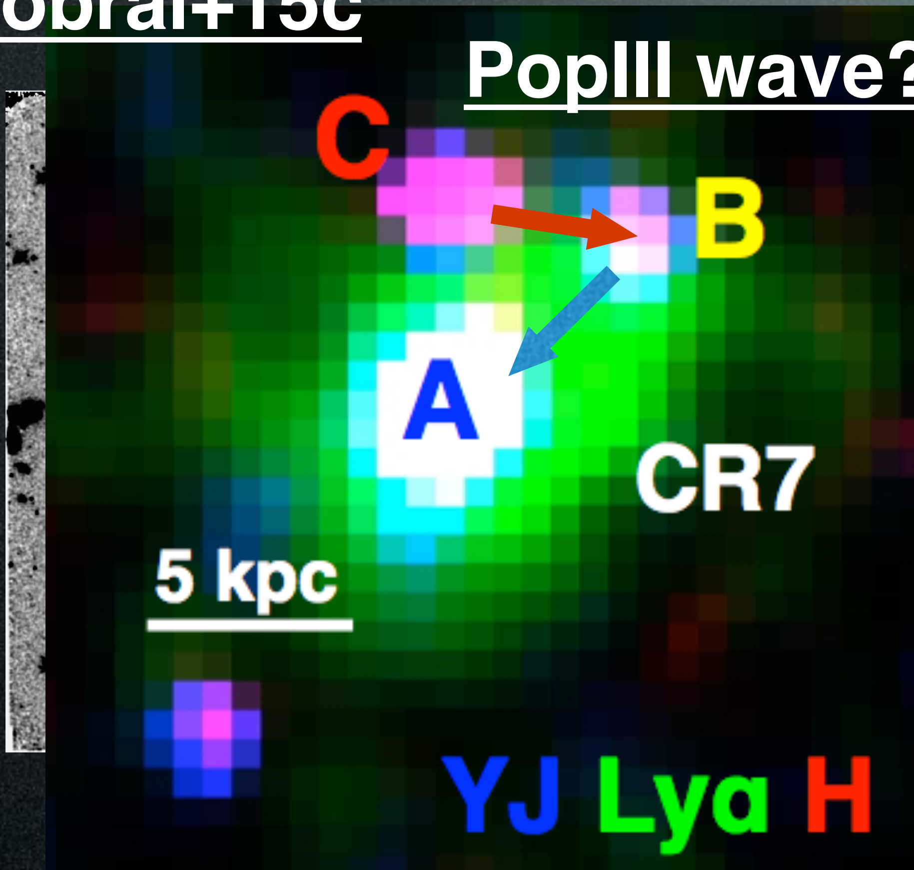
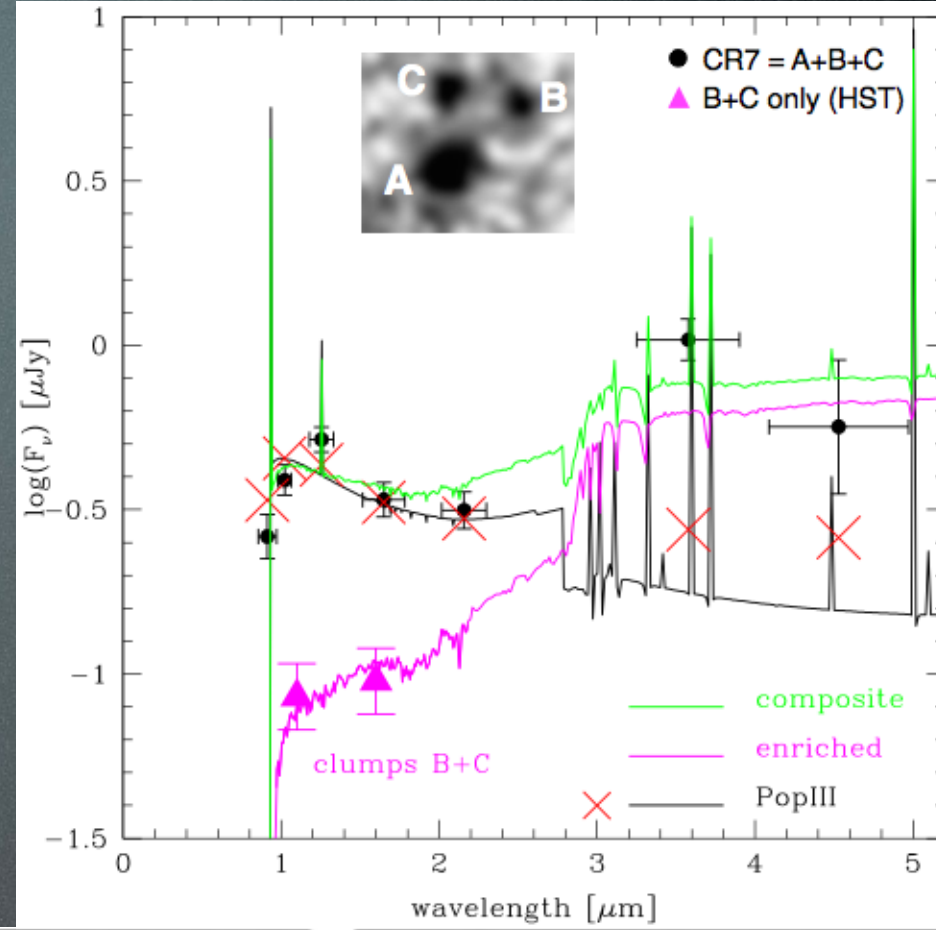
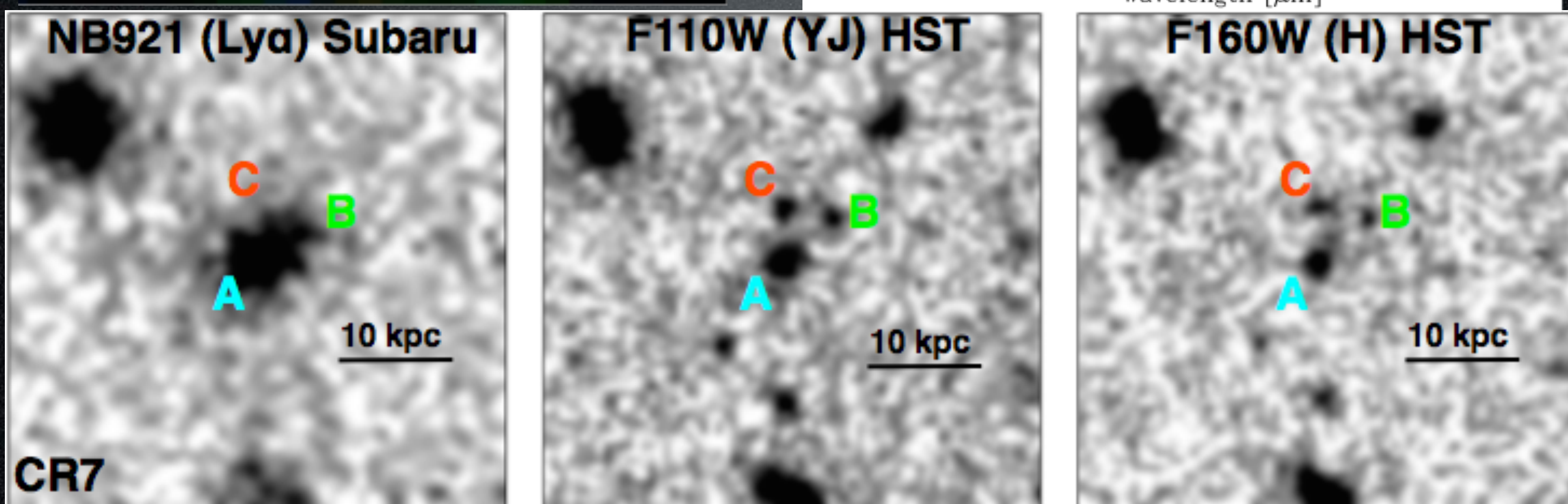




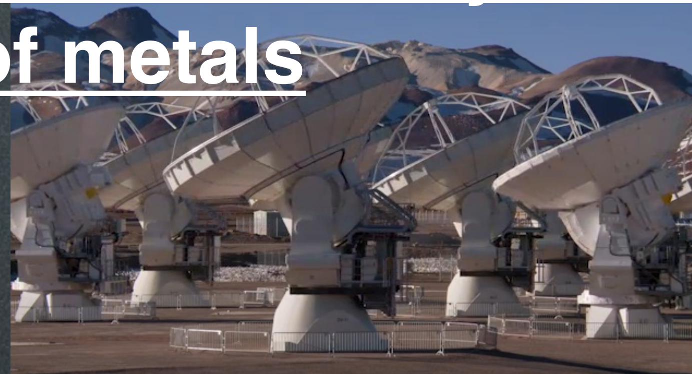
Sobral+15c


PopIII wave?
C
B
A
CR7
5 kpc
YJ Lya H

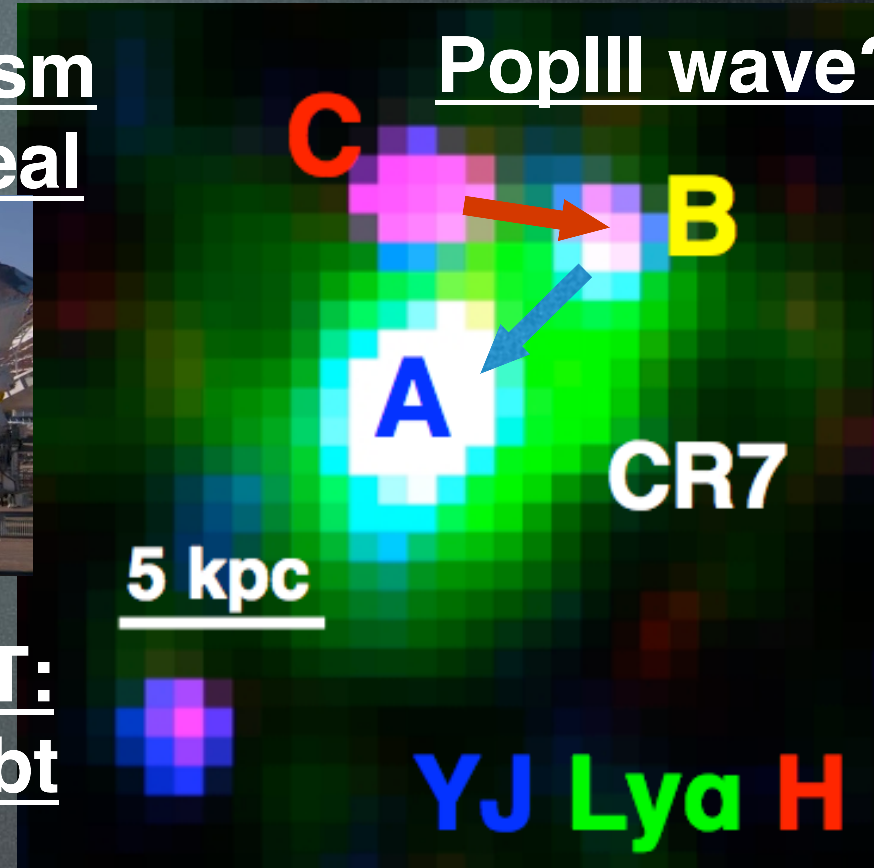

C
B
A
CR7 = A+B+C
B+C only (HST)
log(F_ν) [μJy]
wavelength [μm]
clumps B+C
composite
enriched
PopIII
1
0.5
0
−0.5
−1
−1.5
0
1
2
3
4
5


NB921 (Lyα) Subaru
C
B
A
10 kpc
CR7
F110W (YJ) HST
C
B
A
10 kpc
F160W (H) HST
C
B
A
10 kpc

Follow-up with HST WFC3 Grism + ALMA needed to clearly reveal any traces of metals



PopIII wave?



Ideal first-light targets for JWST: confirm PopIII beyond any doubt from day 1!

… and the potential to find and study the most distant galaxies ever found at z~8.8

There are three possibilities to produce high luminosity, high EW and HeII and Ly alpha nebular lines for CR7:

AGN: This is not x-ray source. No metal lines were Detected in DEIMOS and Xshooter spectra.

WR star: CR7 is not expected to be WR star due to its very narrow HeII line (~100 km/s) compared to a WR stars FWHM of ~3000 km/s

Collapsing BH: the Ly a/HeII is higher by ~2 than what expected if this is due to a BH. Also, there is no broad lines

Take home messages

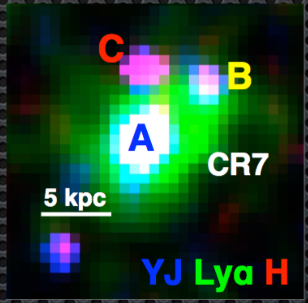
Matthee, Sobral et al. 2015, MNRAS (arXiv:1502.07355)

Sobral, Matthee et al. 2015, ApJ (arXiv next week)

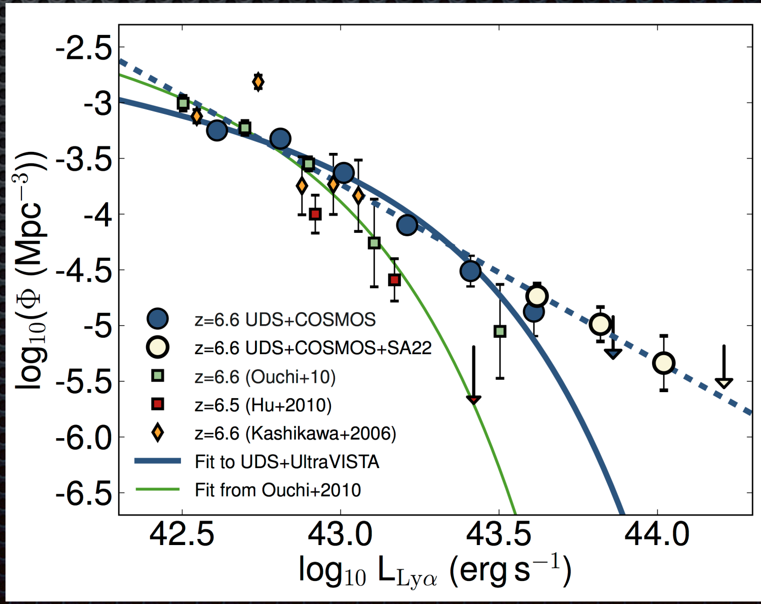
- Luminous Lyα emitters (~$10^{43.5}$ erg/s) at z=6.6 much more common than thought

1.5×10^{-5} Mpc^{-3}

- Evolution of the Lyα LF is mostly at the faint end
- PopIII-like stellar populations in luminous Lyα emitters at z=6.6



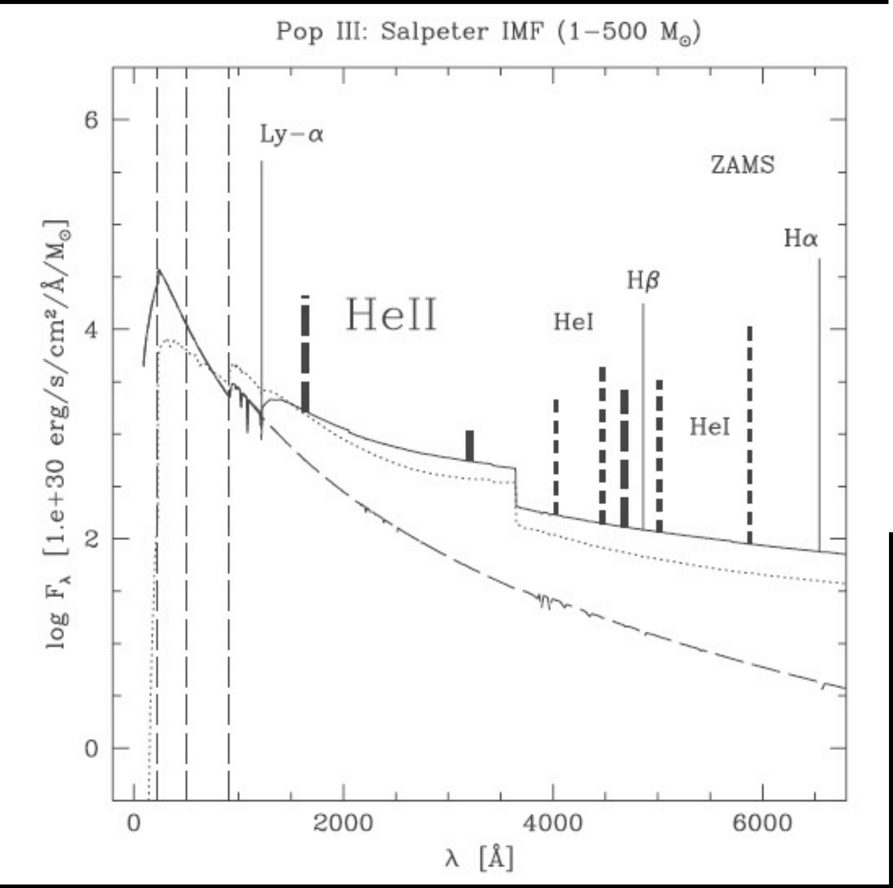
HeII

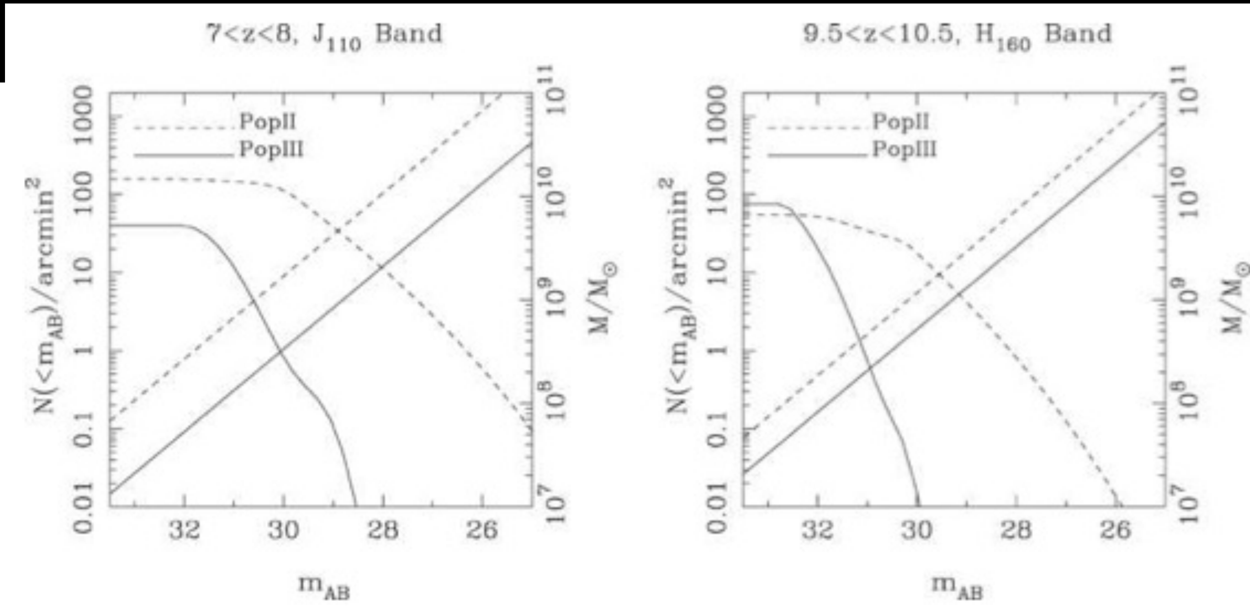


DETECTION OF POP III STARS WITH TMT/IRMS

Number Density of Pop III stars

Detection of He II 1640 A





BROAD IRMS SCIENCE

IRMS can best be used for:

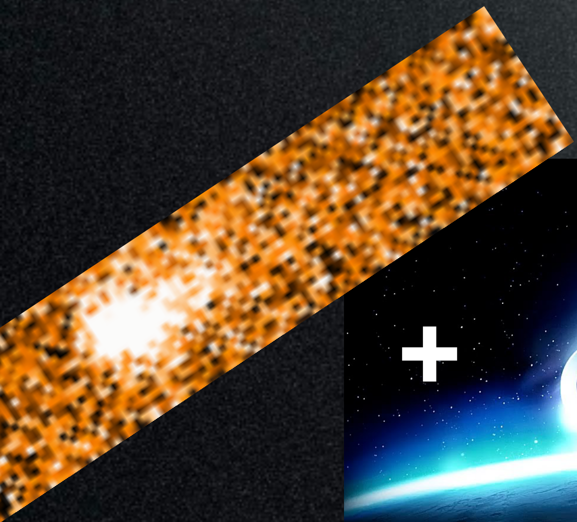
- ✓Near-IR spectroscopy of resolved faint sources (nearby or at high-z)
- ✓Spectroscopy of sources with number densities ~ 10 per $arcmin^2$
- ✓ Spectroscopy requiring low sky background
- ✓ Spectroscopy requiring high spatial resolution
- ✓High spatial resolution imaging of faint sources
- ✓Imaging/spectroscopy of crowded fields
- ✓Narrow-band selection of line-emitting sources

Take home messages

Matthee, Sobral et al. 2015, MNRAS, in press (arXiv:1502.07355)
Sobral, Matthee et al. 2015, ApJ, in press (arXiv:arXiv:1504.01734)

- **Luminous Lyα emitters (~$10^{43.5}$ erg/s) at z=6.6**

$1.5 \times 10^{-5}\ \mathrm{Mpc}^{-3}$ **much more common than thought**



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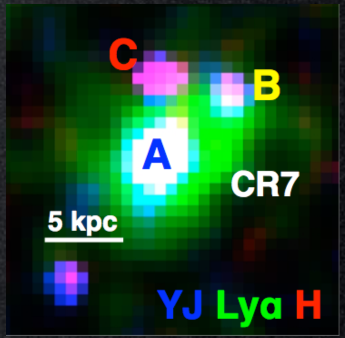

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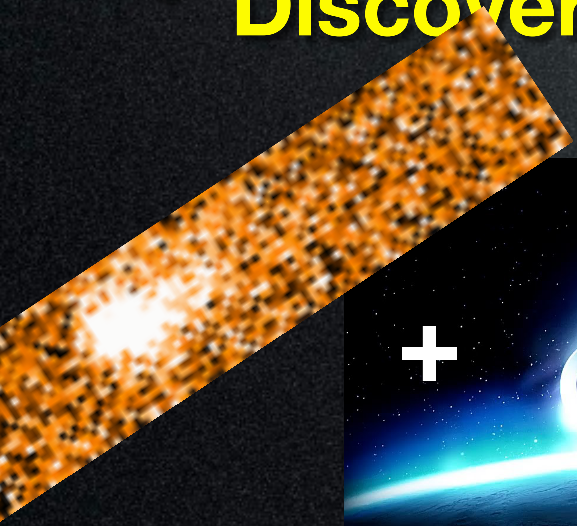
- **Discovery of the most Luminous Lyα emitters at z=6.6: surprises!**



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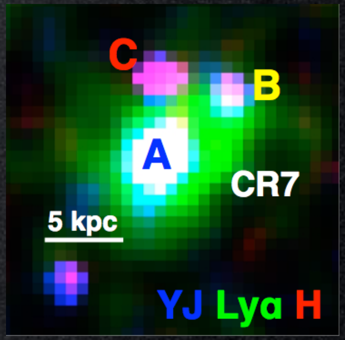

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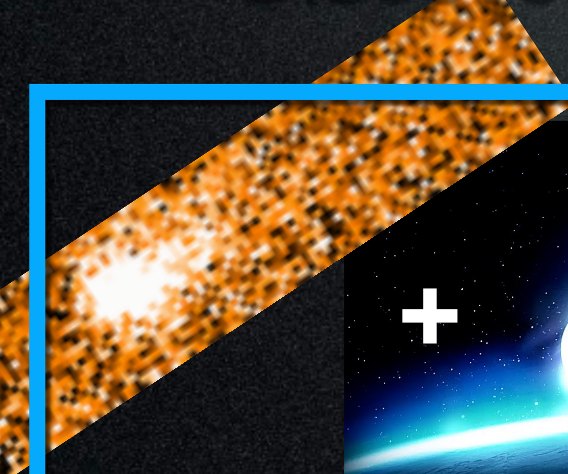

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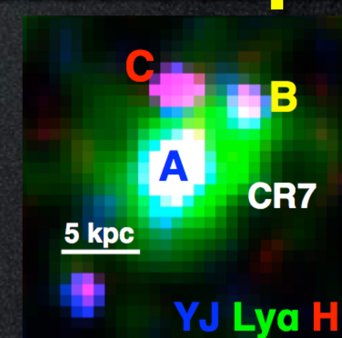

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