BRIGHT LYMAN-ALPHA EMITTERS IN THE EPOCH OF RE-IONISATION

Universiteit Leiden

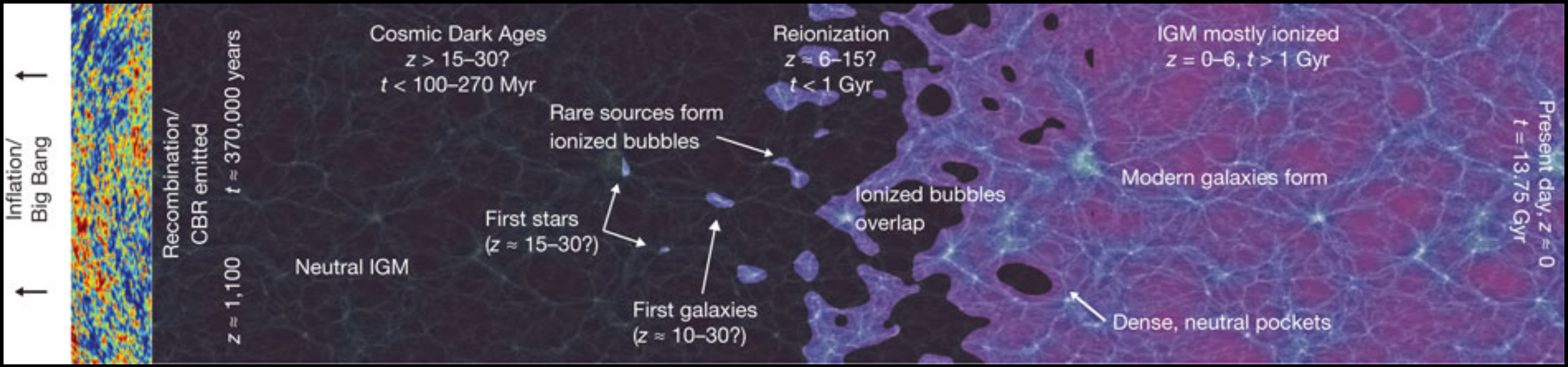
Sterrewacht Leiden

Jorryt Matthee

David Sobral, Sérgio Santos, Behnam Darvish, Daniel Schaerer, Bahram Mobasher, Huub Röttgering

When and how did the first stars and galaxies form?

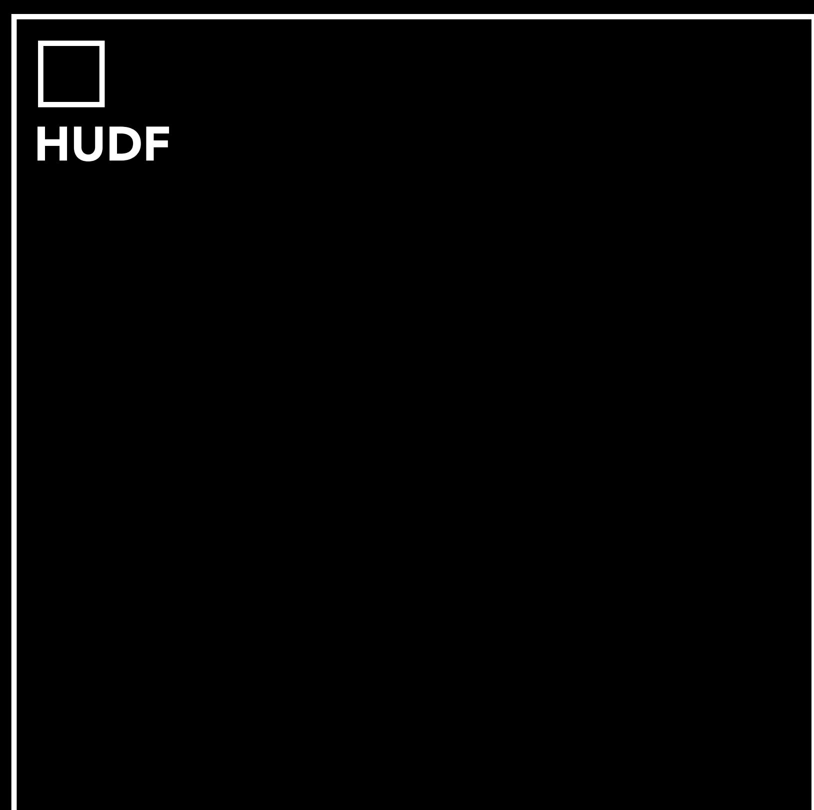
How can we study reionization with galaxies?

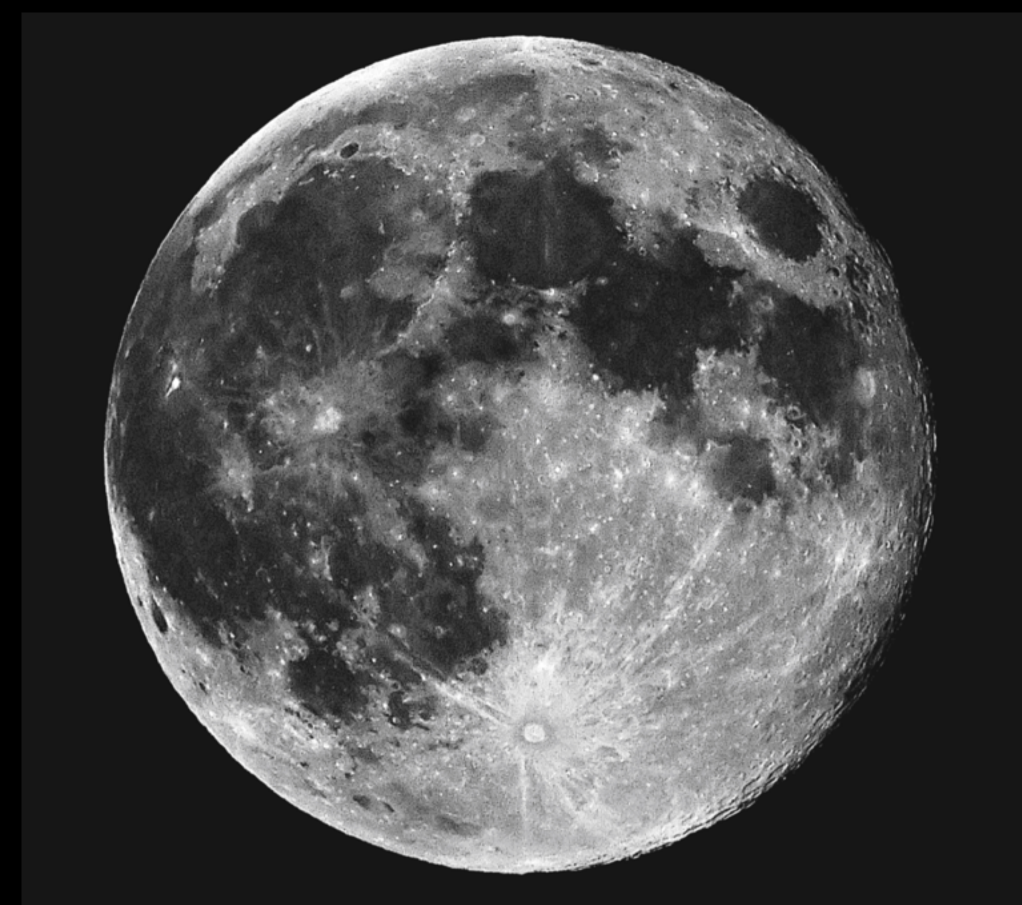


This talk: bright targets which we can study spectroscopically in detail *now*

HST Legacy fields may *not* be the best place to look

- *relatively small volumes*
- *restricted to a single selection technique (broad-band photo-z/Lyman-break)*

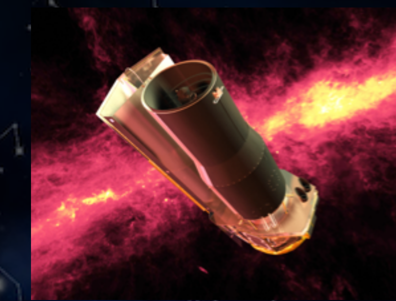


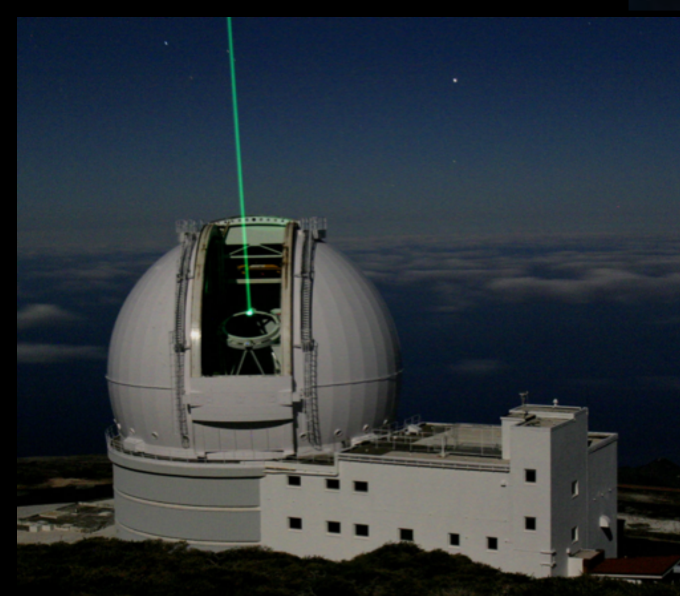


CANDELS+ERS+BoRG (~all HST deep fields)

10,000 galaxies z>3 (e.g. Bouwens+2015), but only handful of bright objects at z>6

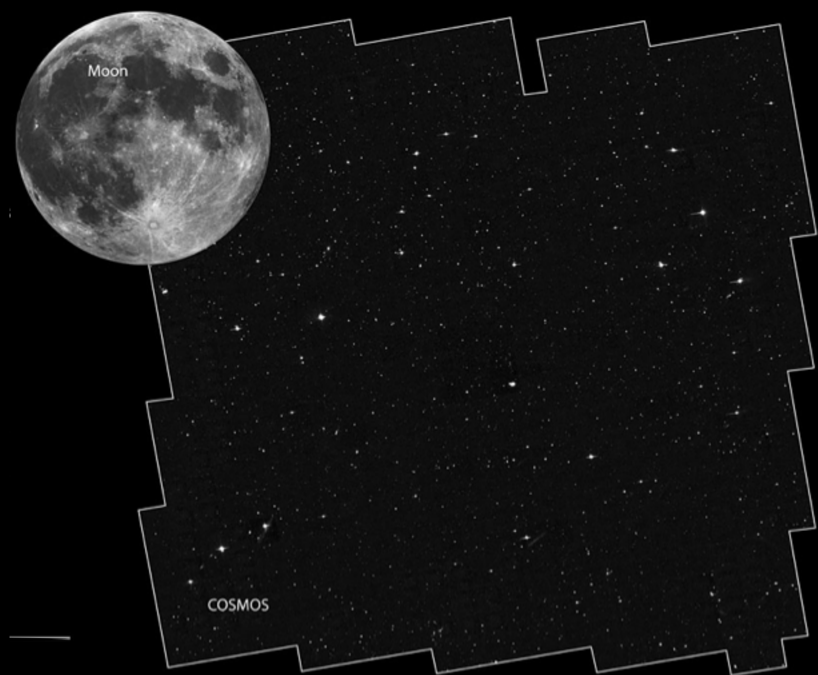
Our approach: ~~very~~ wide fields from the ground

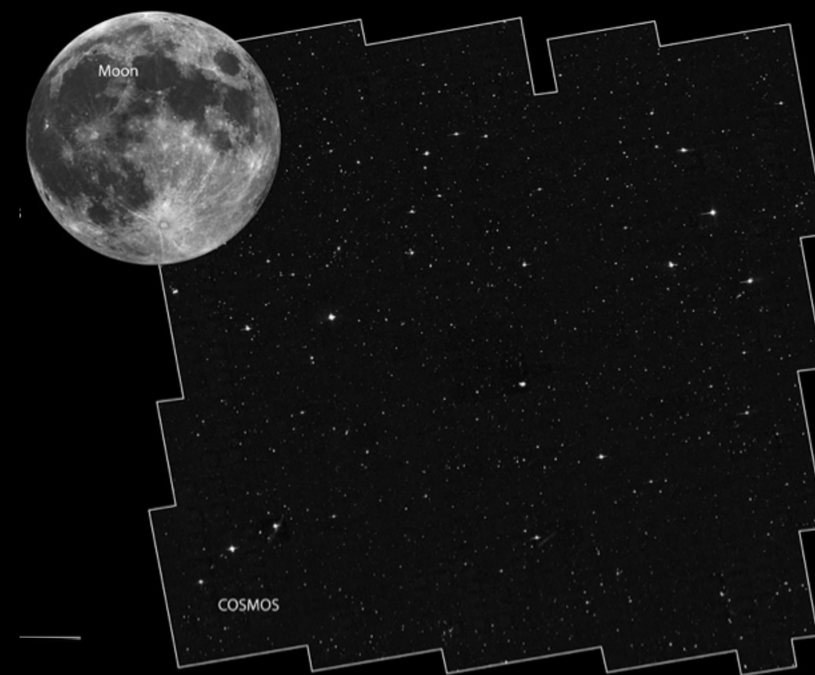


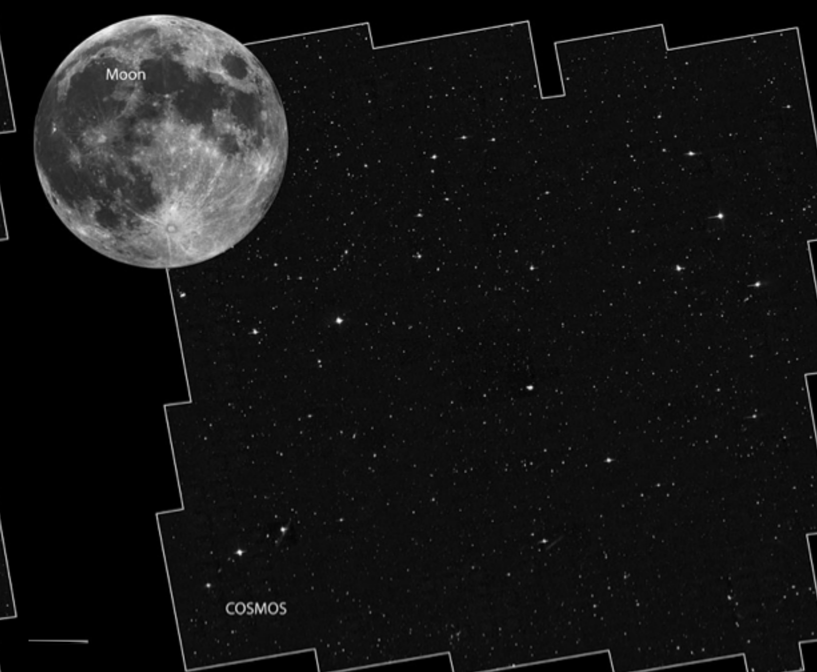


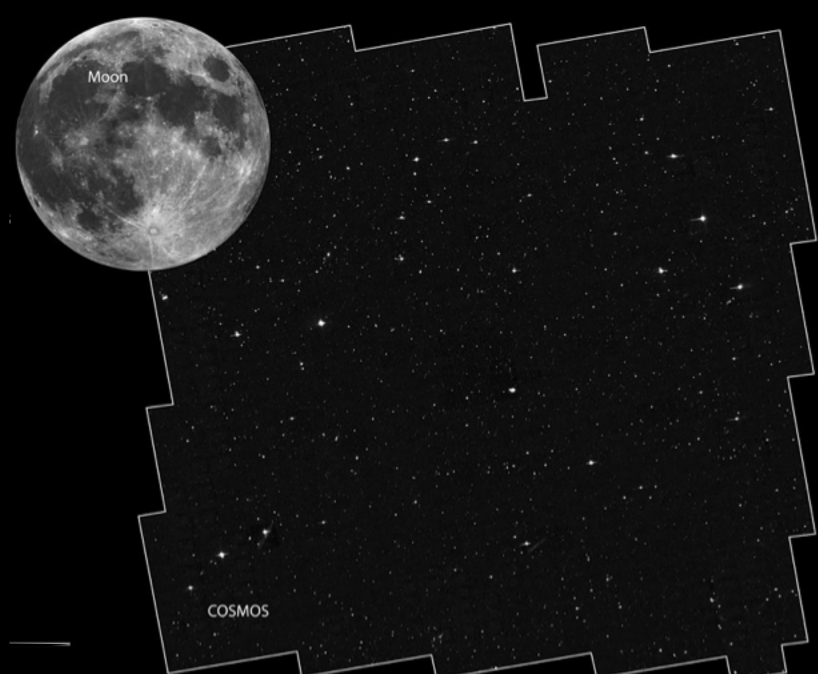
Our typical coverage

COSMOS/UltraVISTA
UDS/XMM-LS
SA22/CFHTLS
Boötes/NDWFS







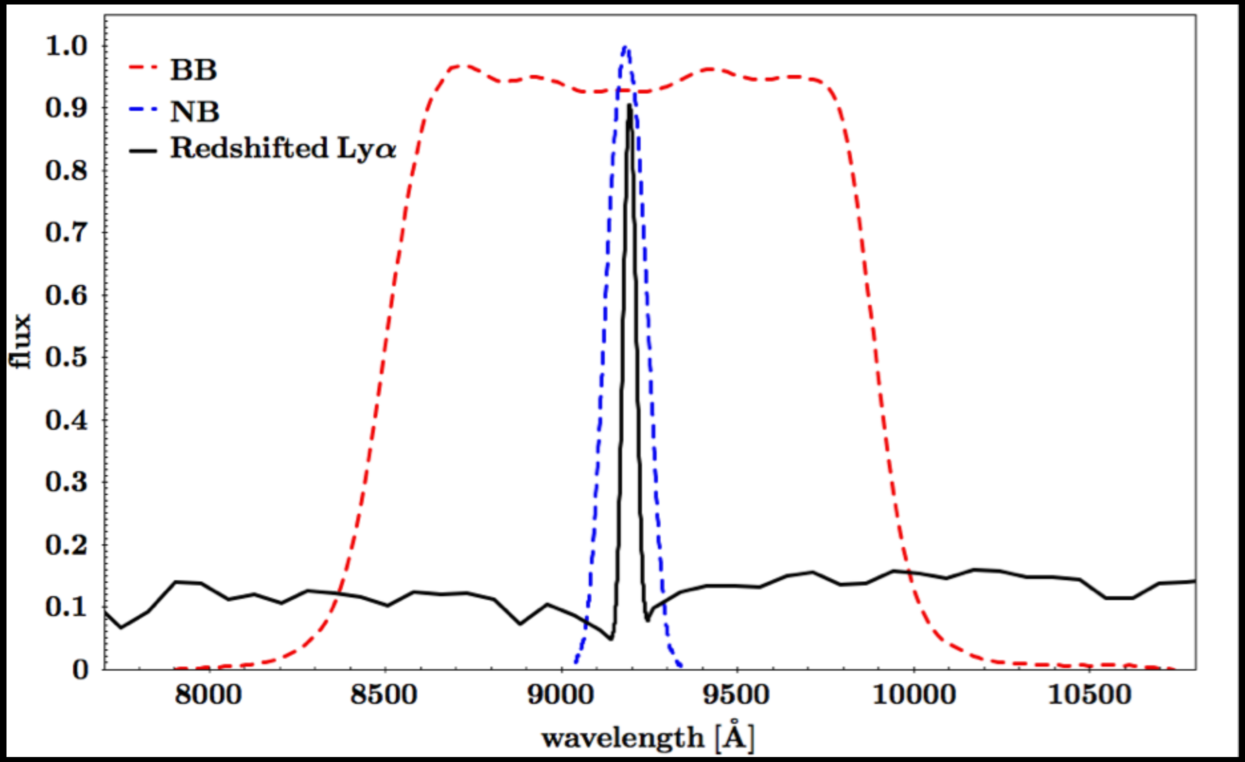


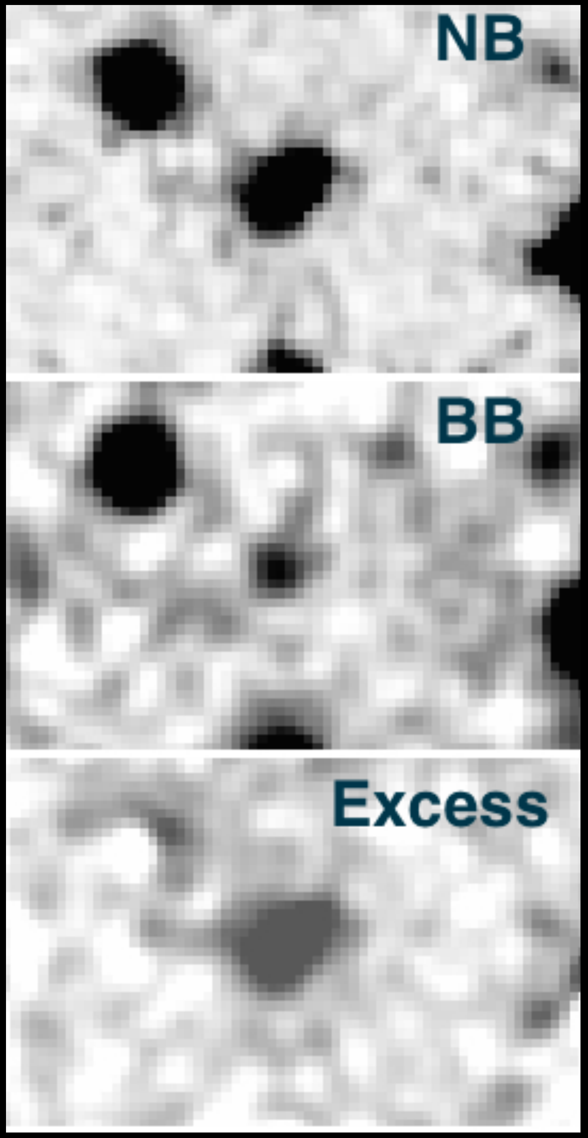
find bright targets

~20 times larger than combined HST fields, ~2 magnitudes shallower

THE NARROW-BAND TECHNIQUE

directly targets galaxies with redshifted Lyman-alpha (1216Å) at z=2.2, 3.1, 4.8, 5.7, 6.6



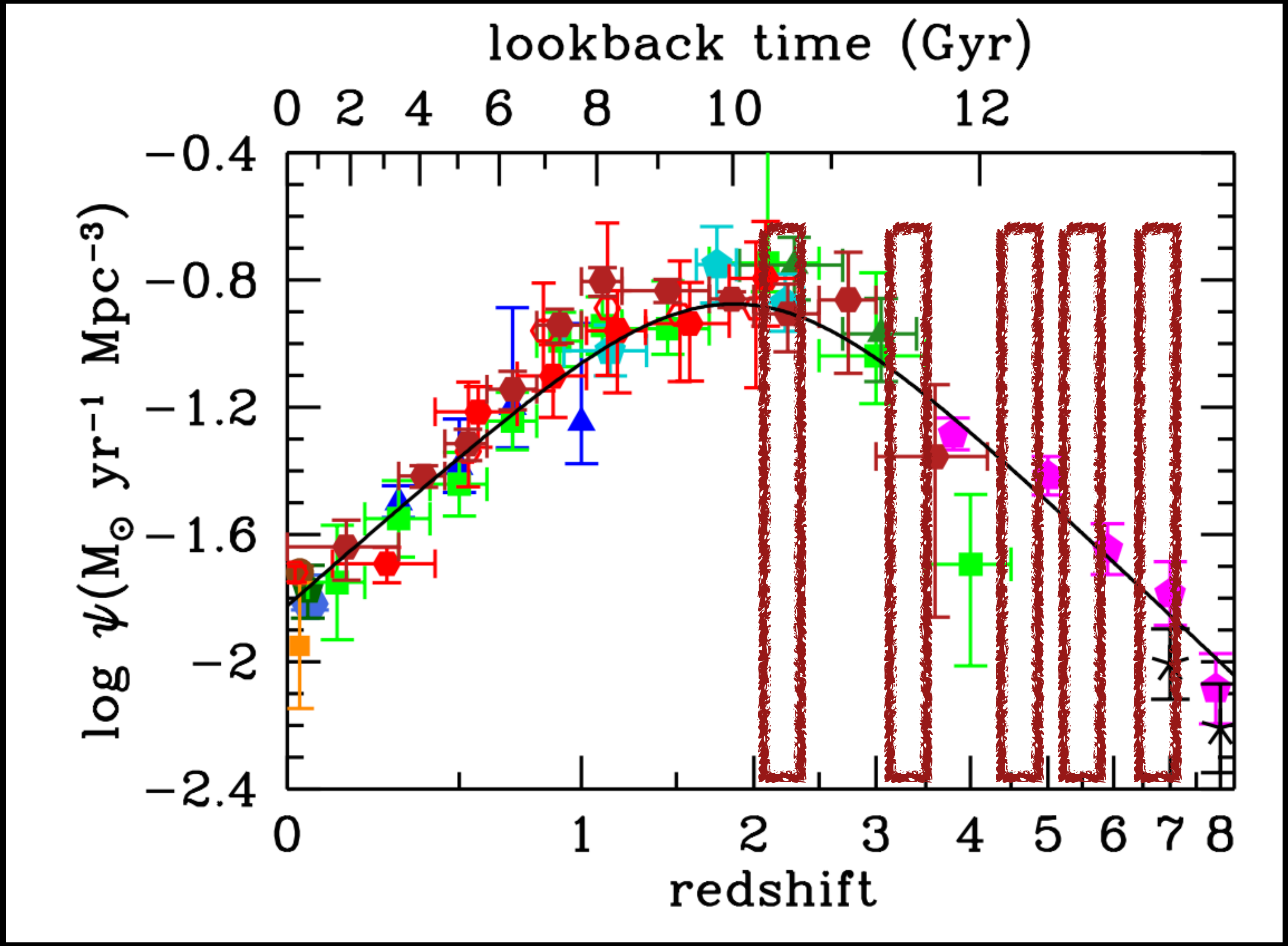


Lyman-alpha typically traces young OB stars, low metallicity (low dust), hot sources

Ouchi+2008,2010; Konno+2014; Matthee+2014,2015; Murayama+2008
Nilsson+2007; Hu+2011; Malhotra&Rhoads2000,2004; Hayes+2010, +++

sources which can be followed up *easily*

The set of wide-field NB surveys



Madau & Dickinson, 2014

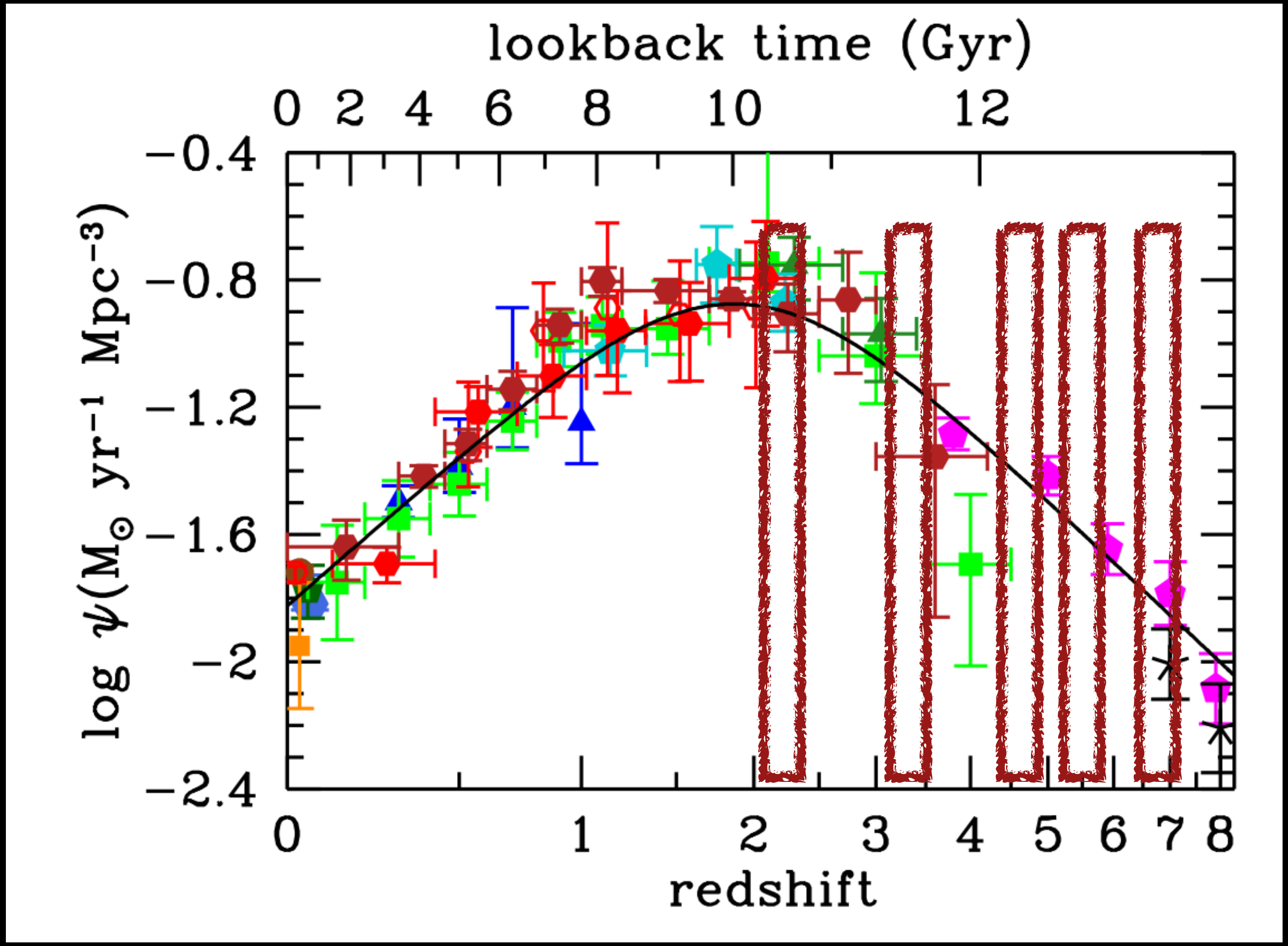
z=2.2: 1.2 deg^2 CALYMHA — matched to Halpha; Sobral, JM+ in prep

z=3.1/4.8: ~25/4 deg^2 ongoing with INT/Subaru + Keck/WHT follow-up

z=5.7: 7 deg^2 Santos, Sobral & Matthee, 2016 arXiv:1606.07435

z=6.6: 5 deg^2 Matthee+2015, MNRAS, 451, 4919 (arXiv:1502.07355)

The set of wide-field NB surveys



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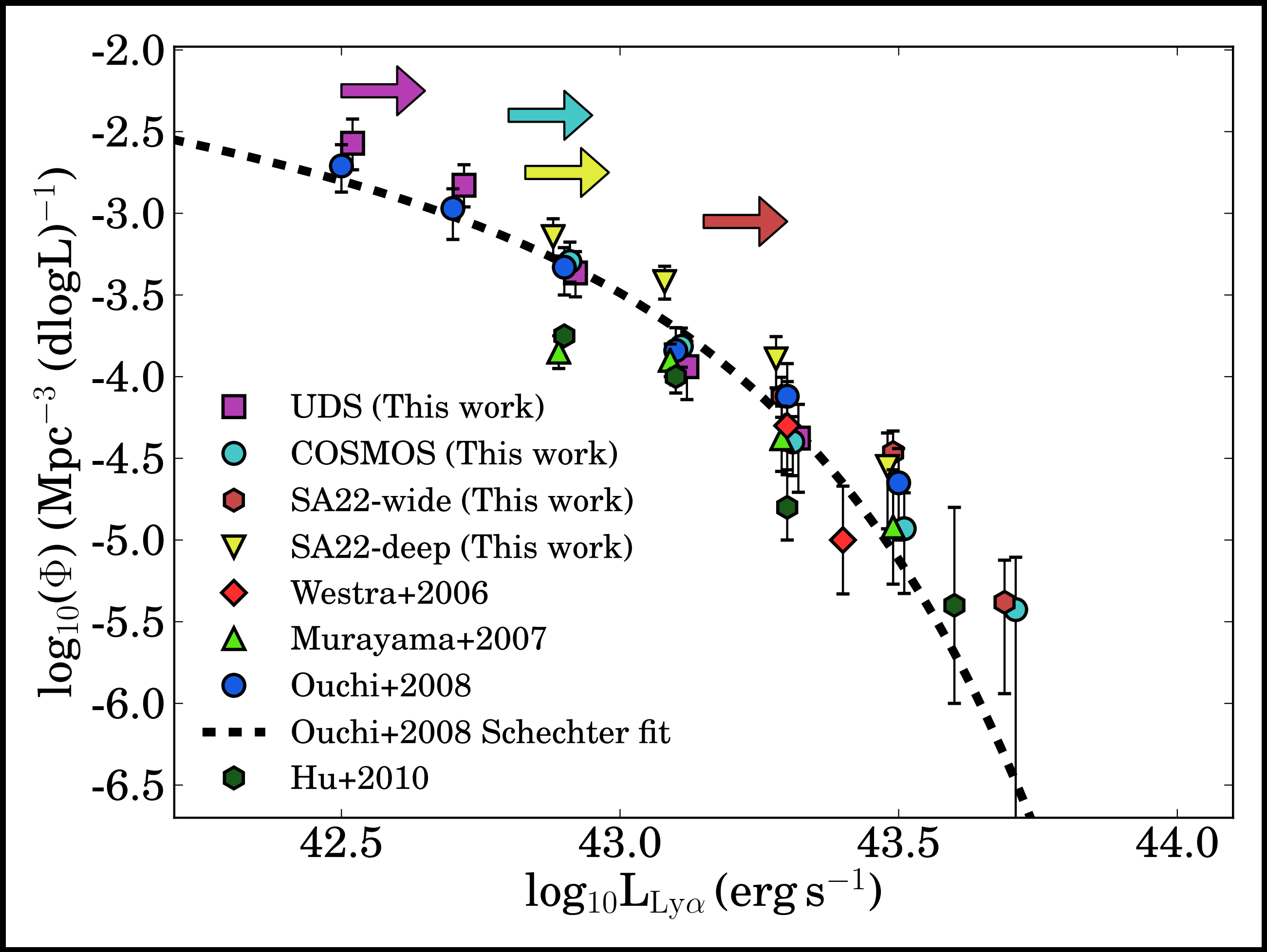
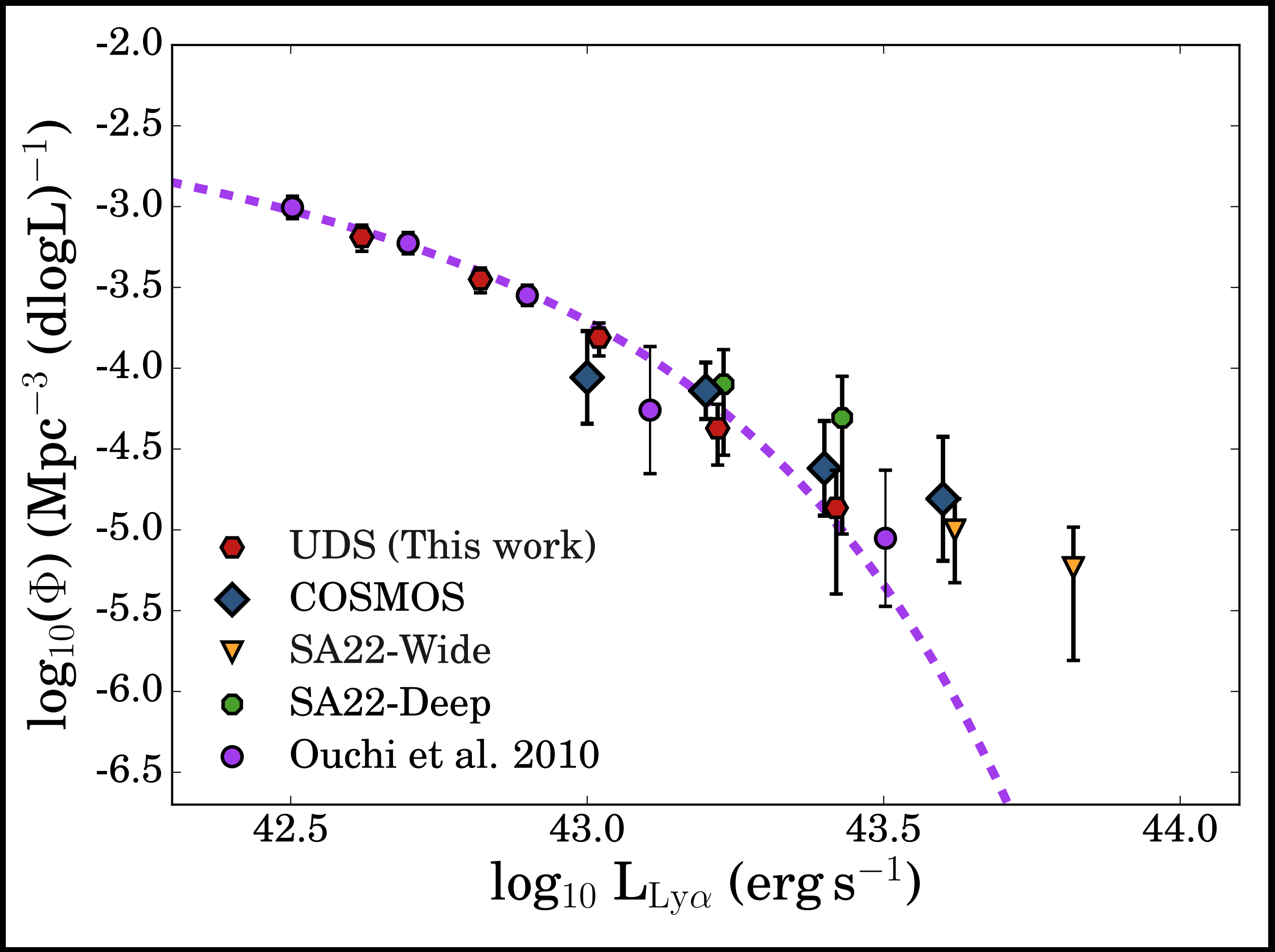
DIFFERENT SURVEY FIELDS: COSMIC VARIANCE

z=5.7 LAE LF:



z=6.6 LAE LF:

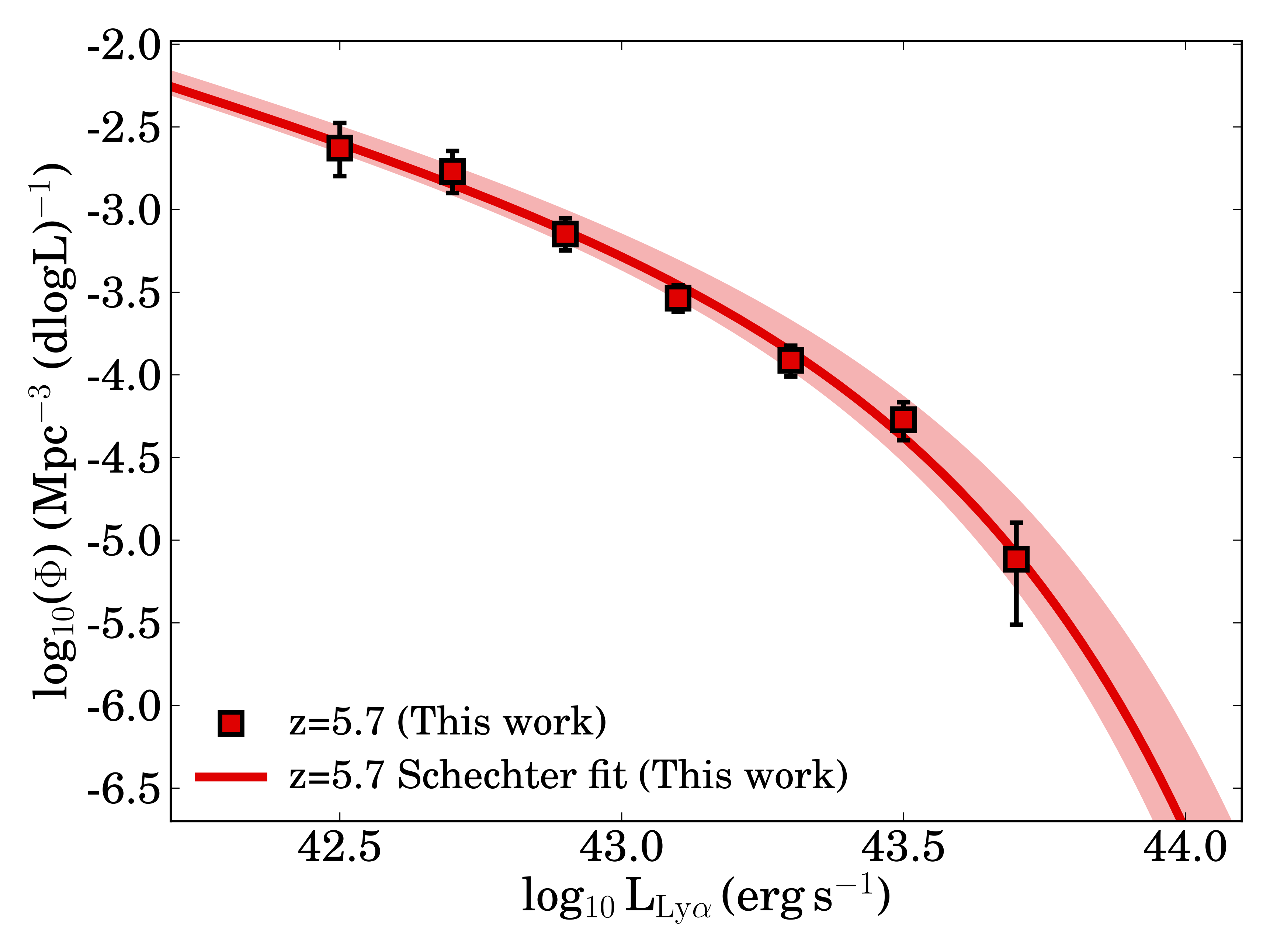


Selection: EW_0(Lya) > 25 Å & Lyman-break, 2" apertures

Allows to study changes in Lya luminosities (due to reionization?)

No selection biases of which UV searches suffer (c.f. Stark+2016, arXiv 1606.01304, talk by Oesch)

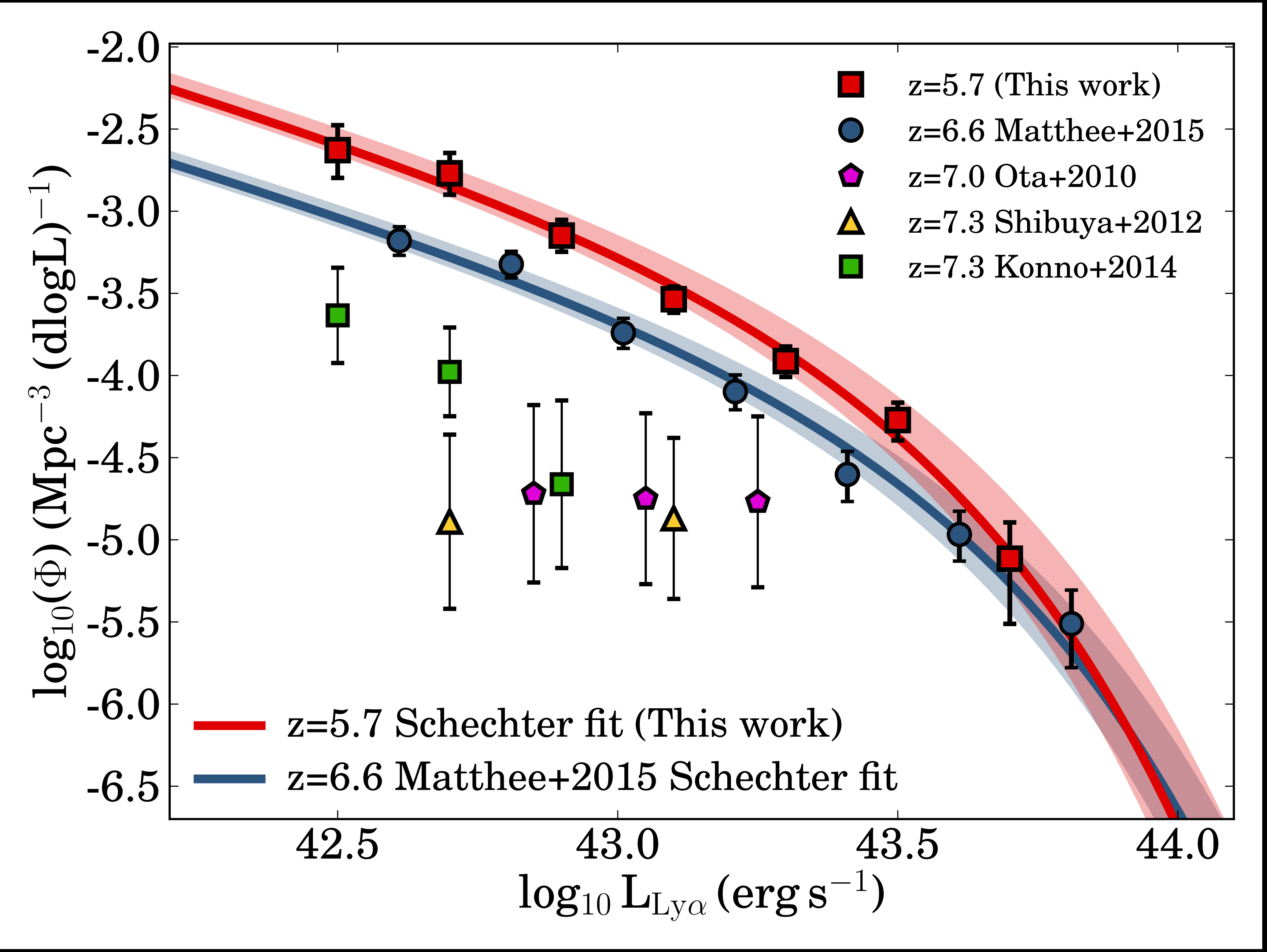
COMBINED Z=5.7 LAE LF



alpha very steep: -2.3+-0.4 (consistent with Dressler+2015)
(c.f. -1.9 UV LF Bouwens+2015; theoretically argued by Gronke+2015)

Santos, Sobral & Matthee, 2016, arXiv: 1606.07435

Evolution of the Lya LF from z=5.7-6.6 and beyond



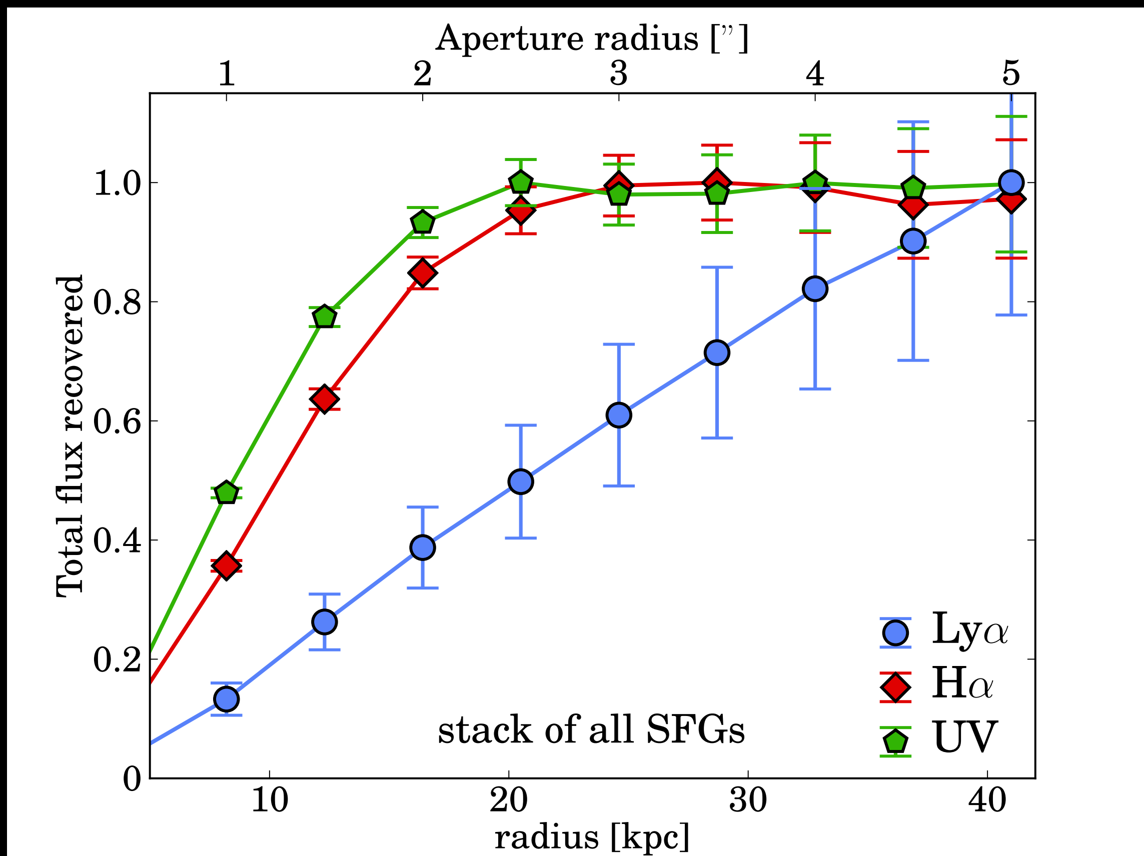
Number density evolves at the faint end, not at the bright end!

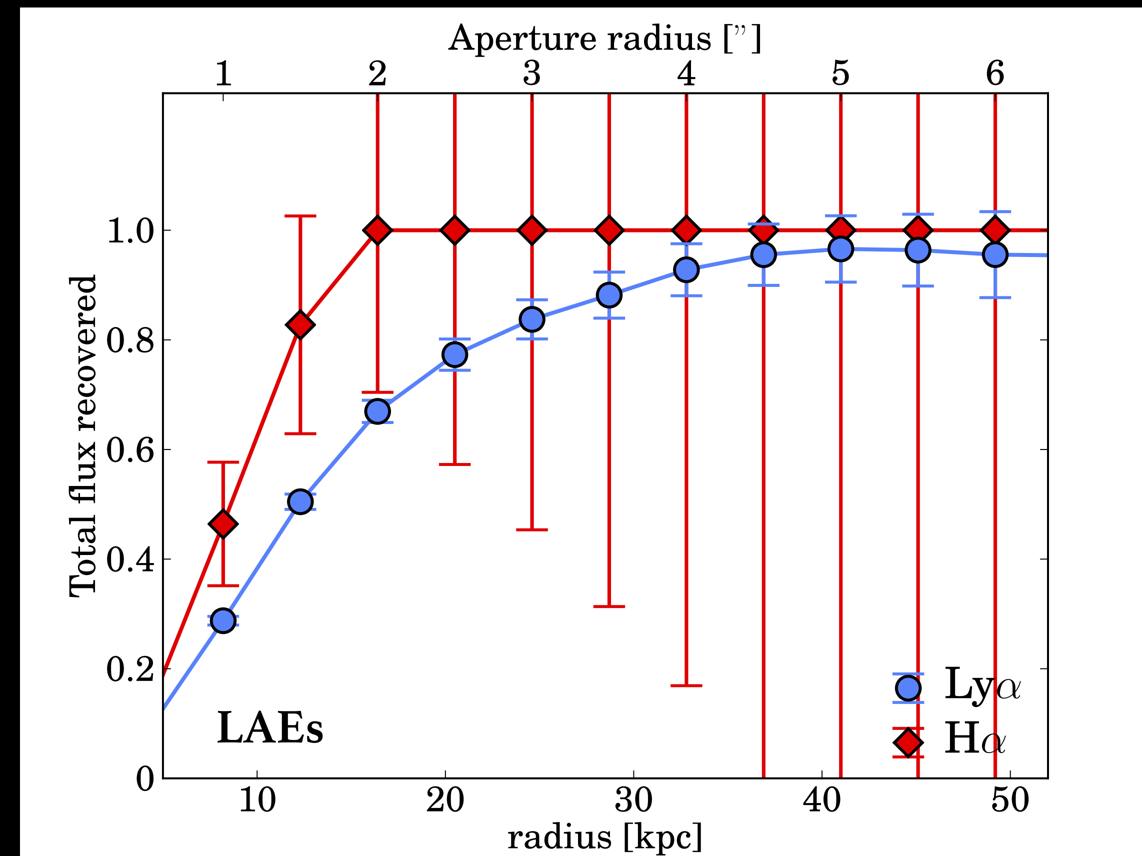
> more neutral IGM scatters Lya out of line-of-sight?

- No comparable wide survey z>7 yet.

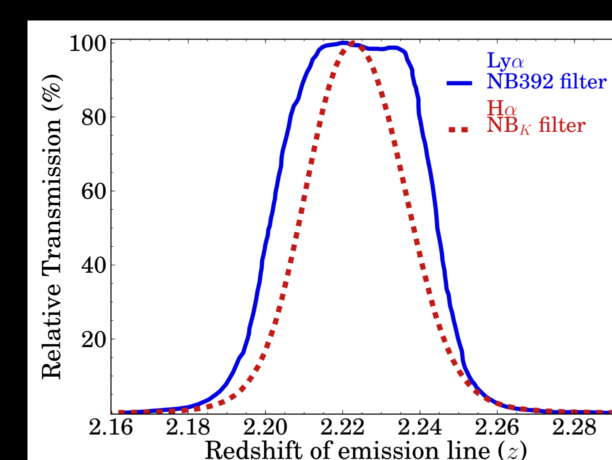
Santos, Sobral & Matthee, 2016, arXiv: 1606.07435

What about extended emission?





At z=2.2, we find that Lya continues to increase up to 30kpc radii at least



$f_{esc,Lya}$ (15kpc): HAEs: 1.6%; LAEs: 42%

SFRs: ~30 M_{sun}/yr vs 7 M_{sun}/yr

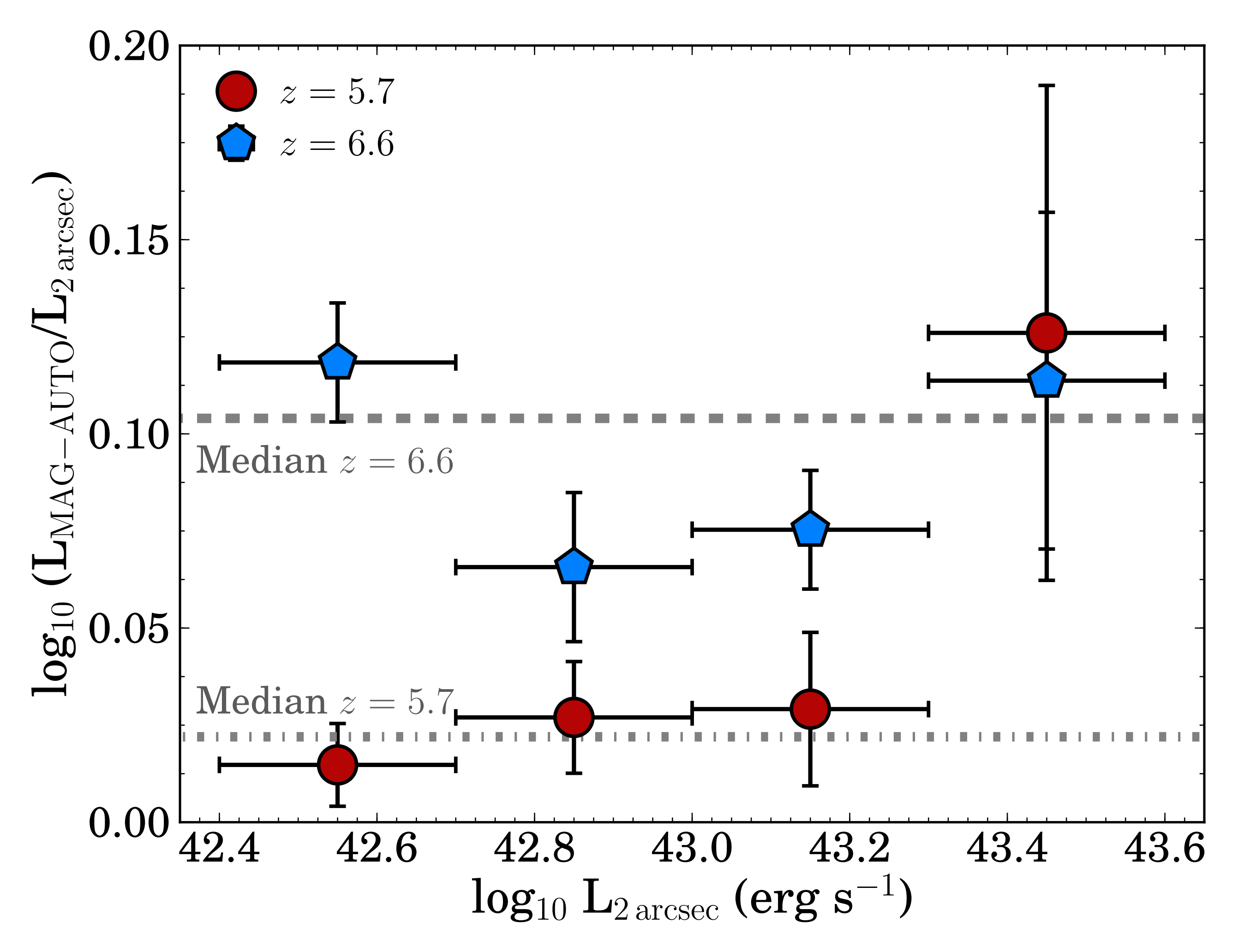
CALYMHA: Matthee+2016a, MNRAS, 458, 449; Sobral, JM+ in prep

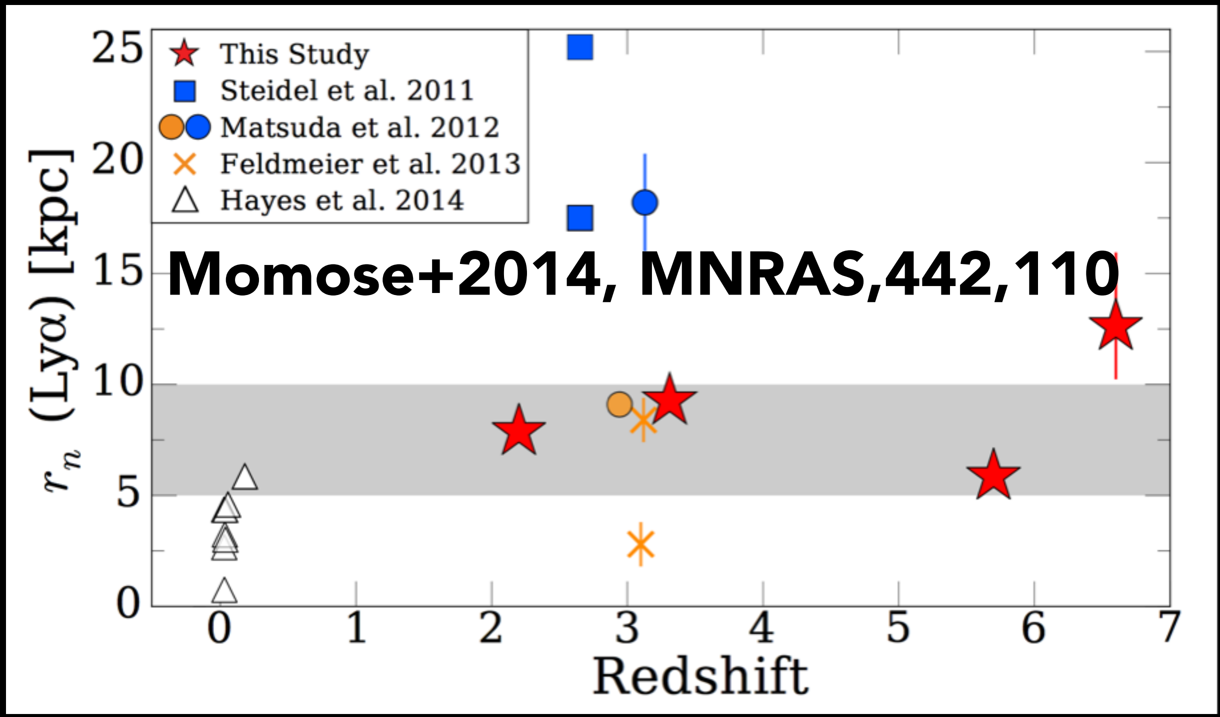
extended Lya for LAEs/LBGs see also e.g. Rauch+2007, Steidel+2011,Momose+2014, Wisotzki+2016

Extended emission at z=5.7-6.6

Simple analysis: Mag-auto luminosity vs 2″ aperture luminosity

Faint LAEs become more extended at z=6.6!

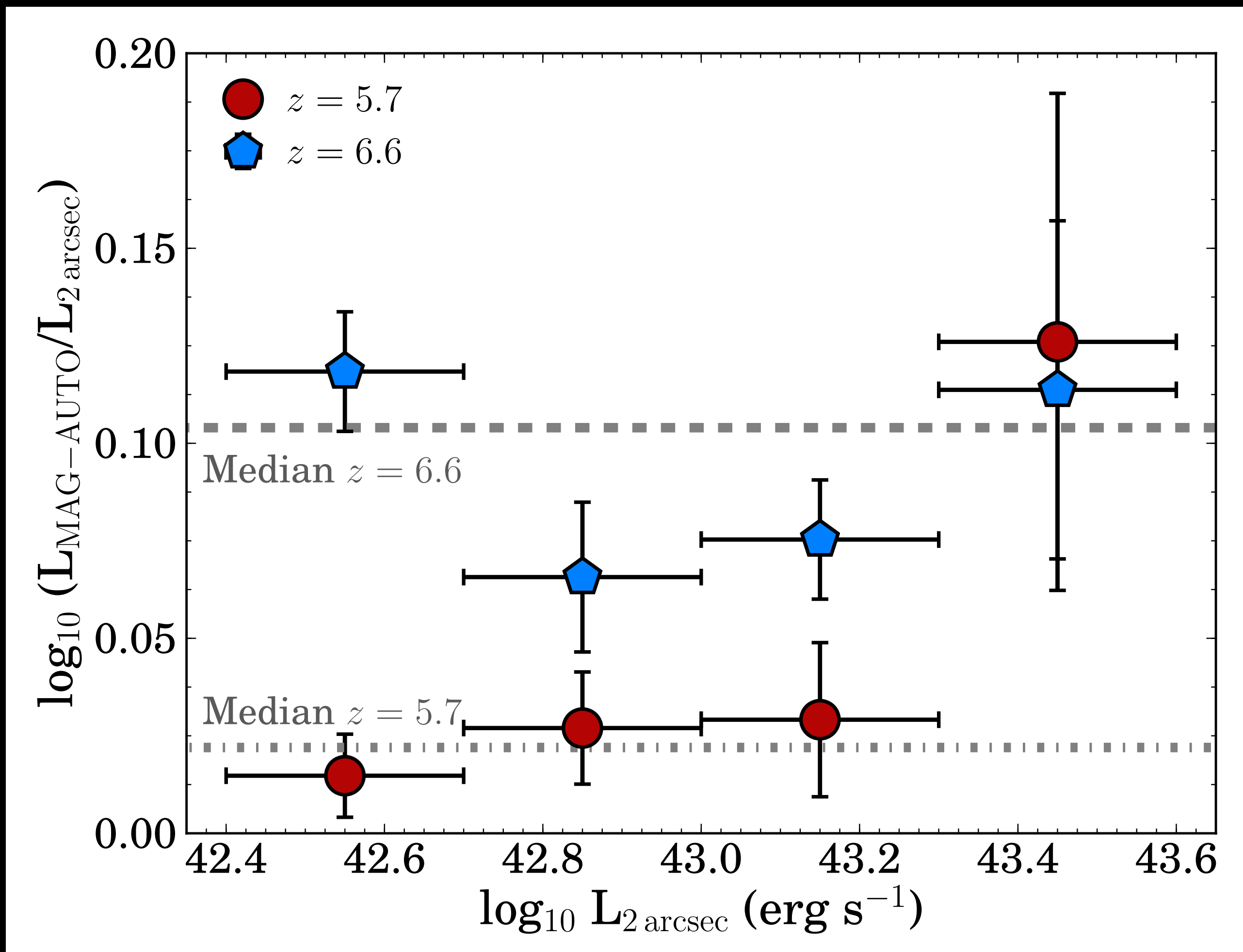


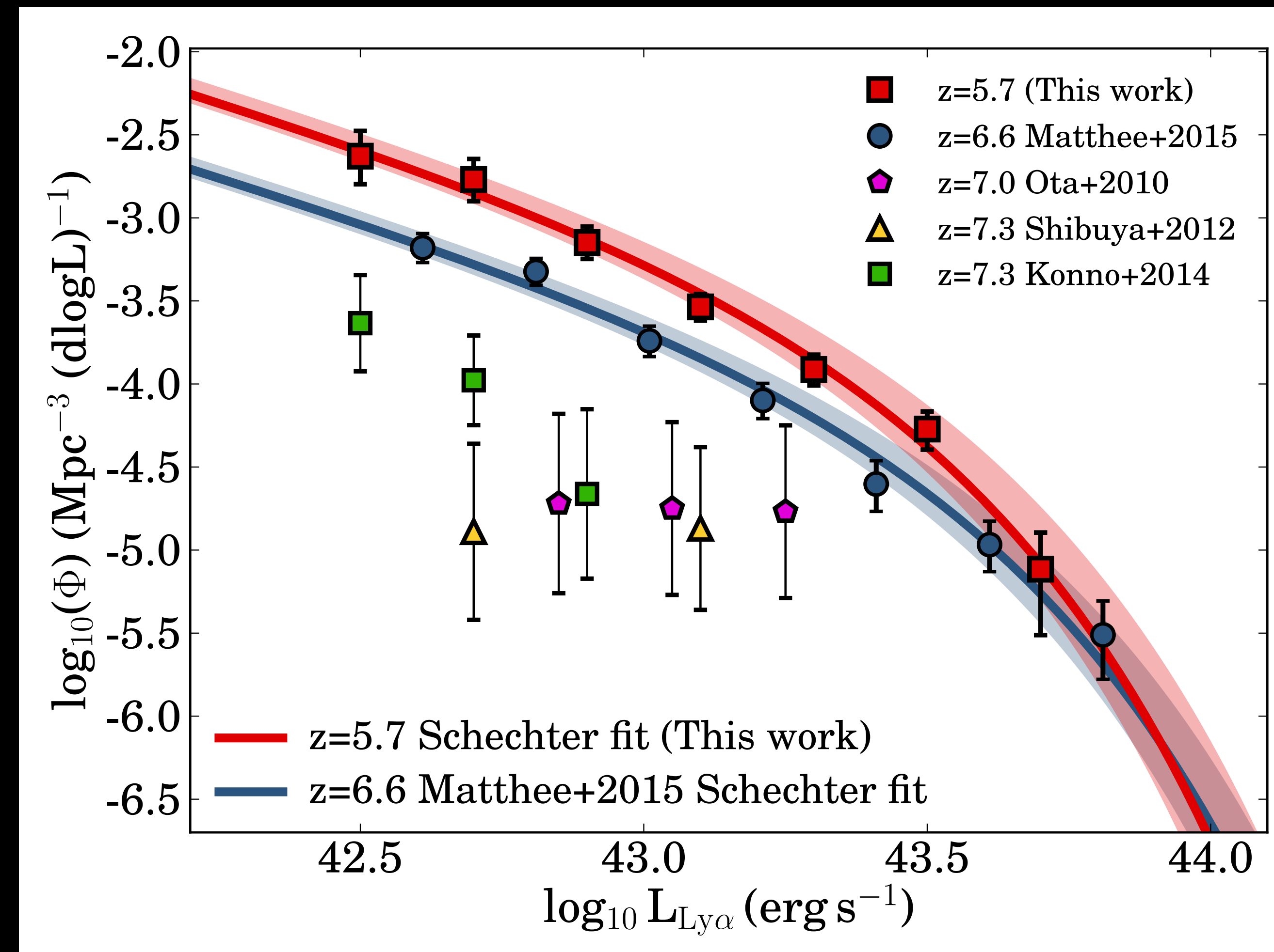


Similar to Momose+2014: median LAE in UDS more extended at z=6.6 than at z=5.7

Santos, Sobral & Matthee, 2016, arXiv: 1606.07435

Observing patchy reionization?





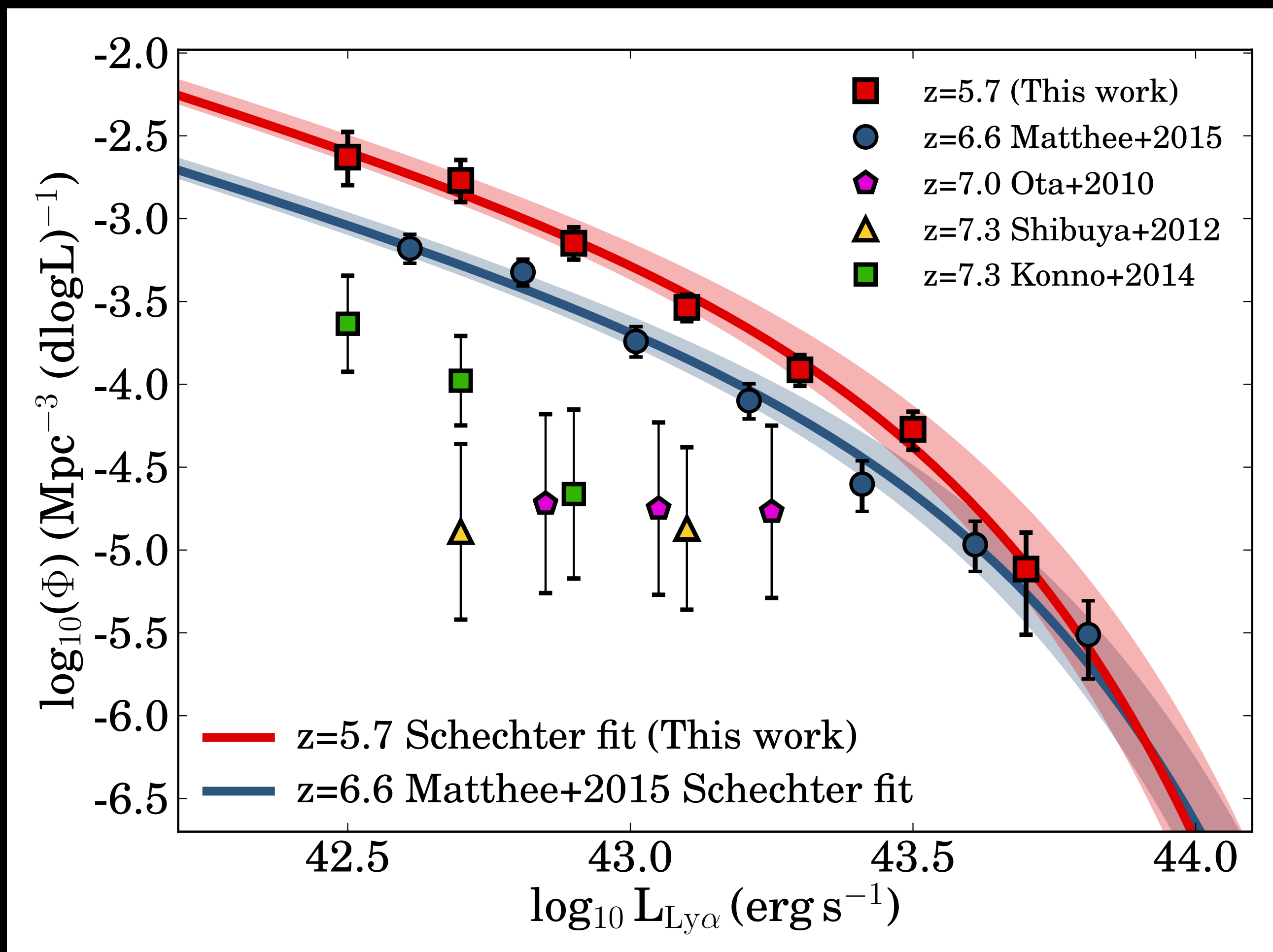
1. Faint LAEs are less abundant and more extended at z=6.6 than at z=5.7
2. Bright LAEs equally abundant and equally extended

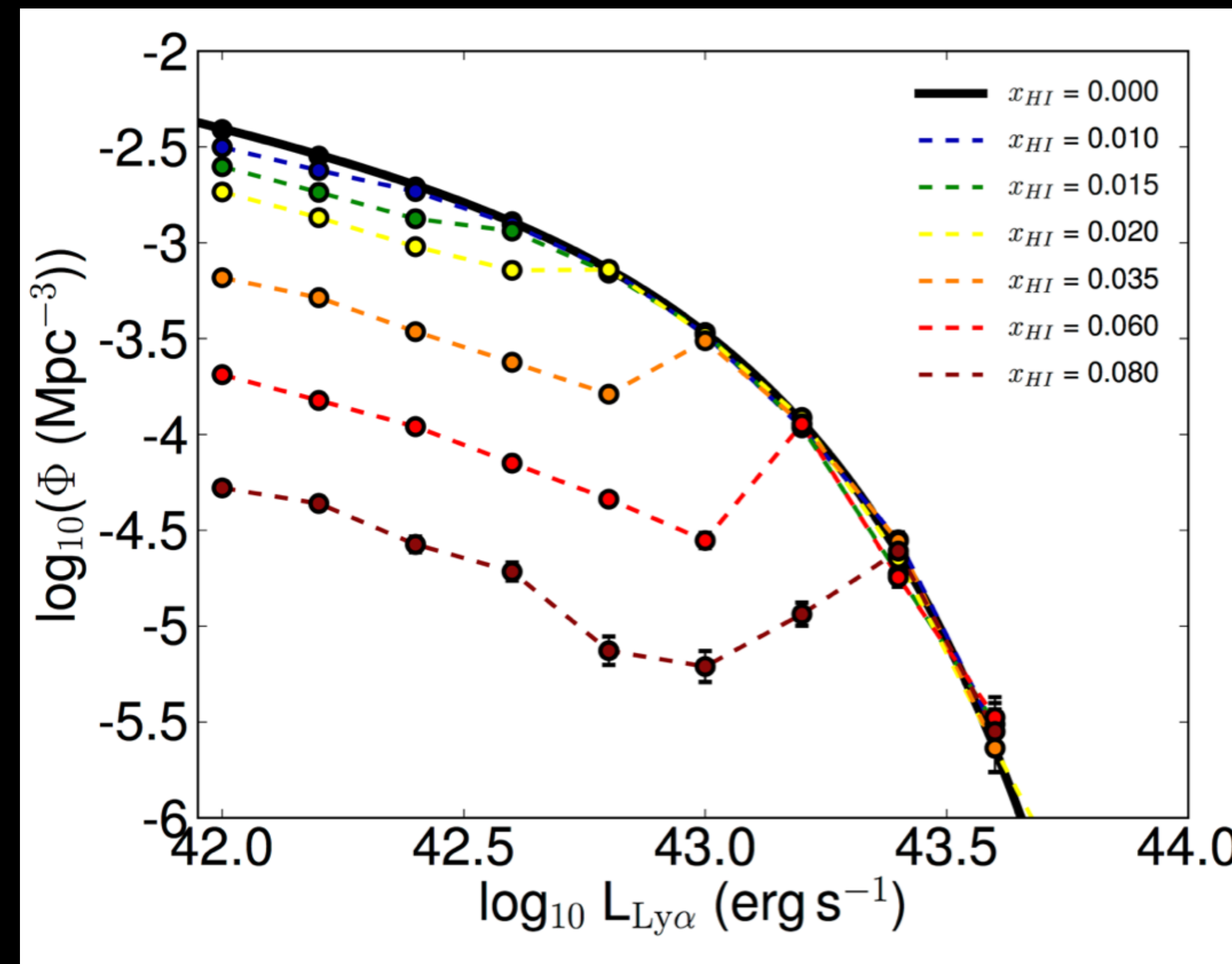
Matthee et al. 2015 MNRAS 451, 4919

Santos, Sobral & Matthee, 2016, arXiv: 1606.07435

Matthee+2015 toy-model: more luminous LAEs easier to observe

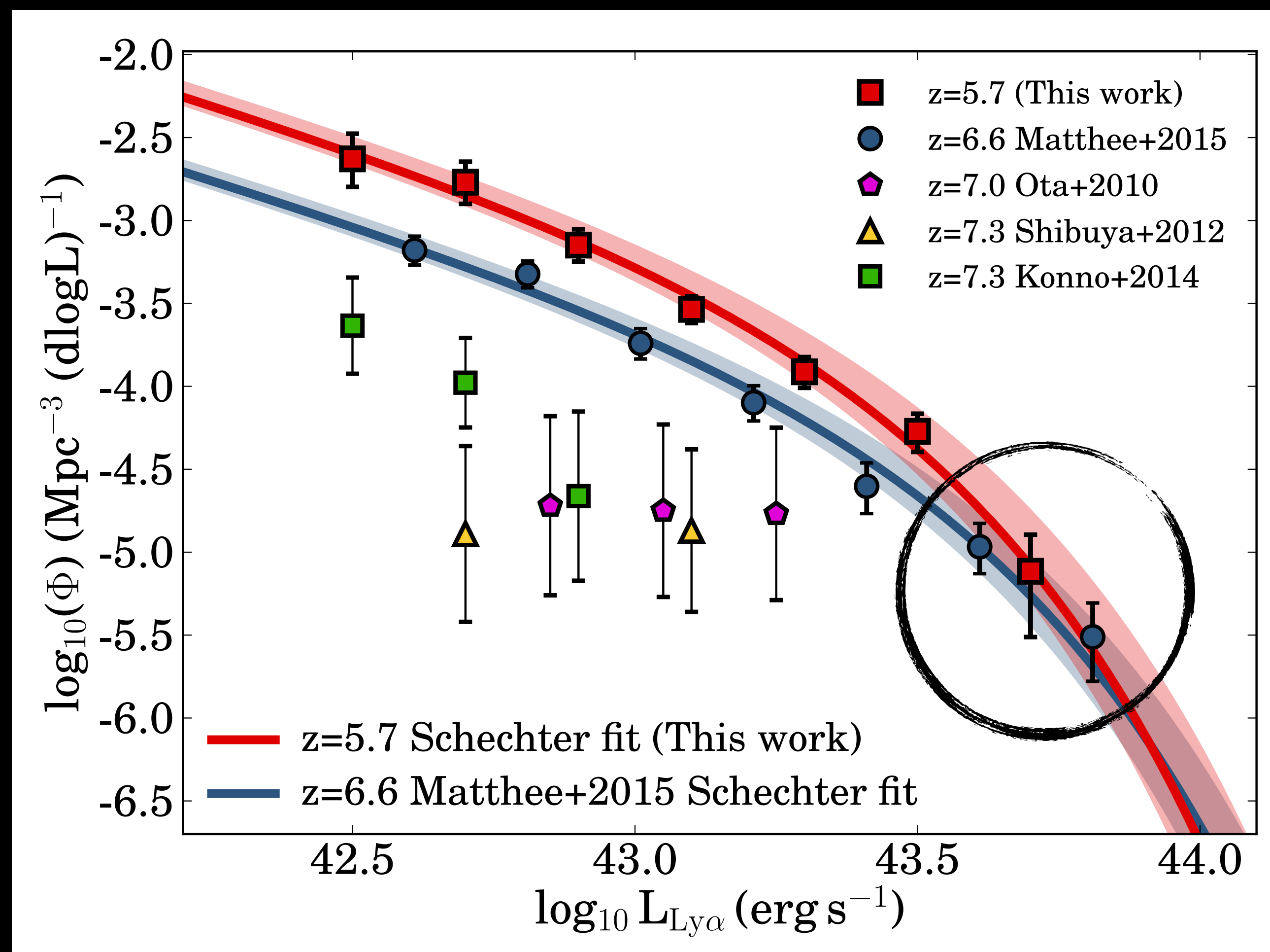
re-ionisation? clustering needed!



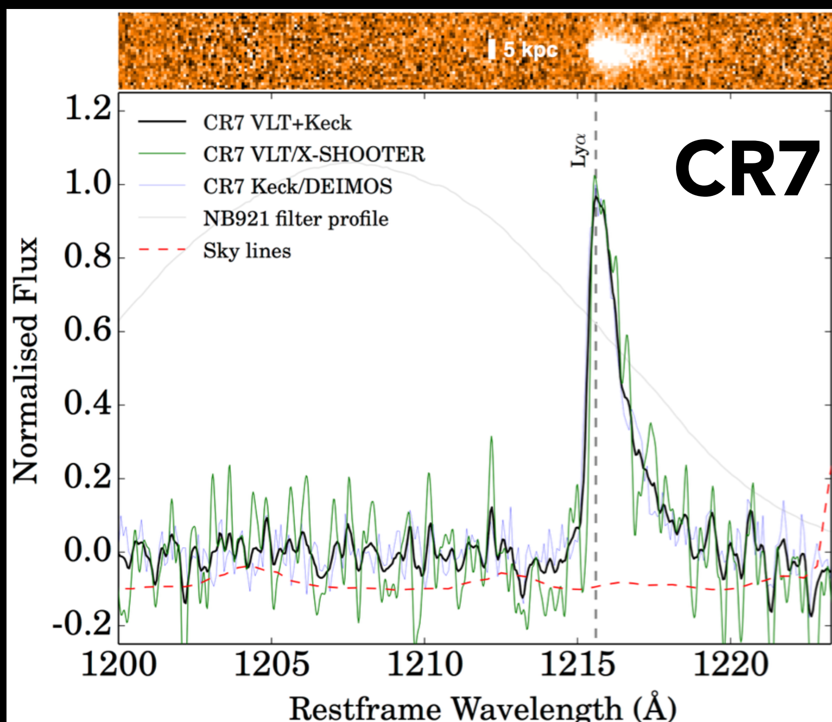


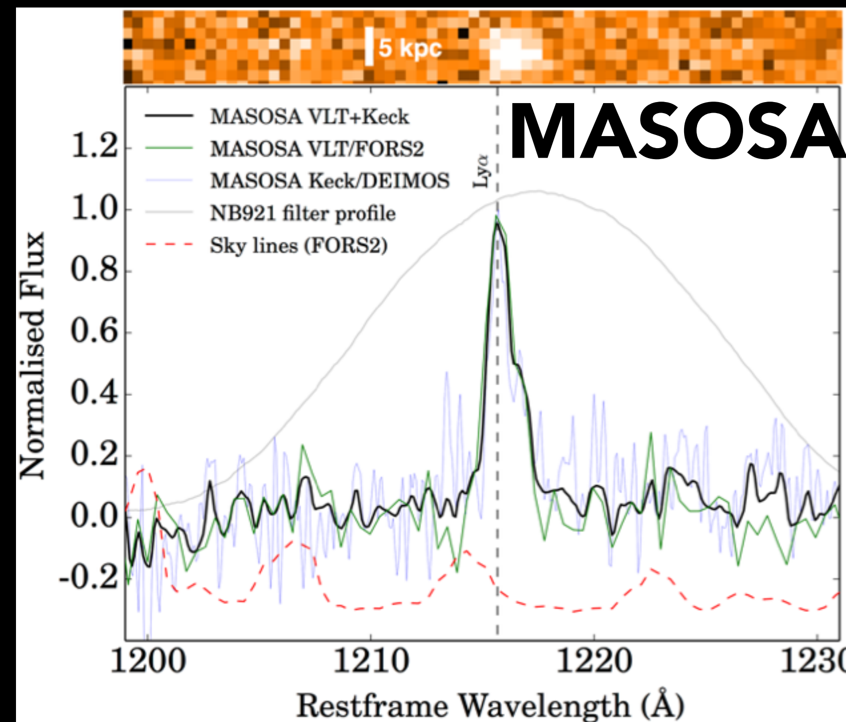
Drop in Lya LF similar to evolution in follow-up of faint UV selected galaxies:
less Lya for L* UV selected galaxies, except when you select on neb. lines in IRAC
(e.g. Ono+2010, Schenker+2014, Pentericci+2014, Schmidt+2016; c.f. Stark+2016)

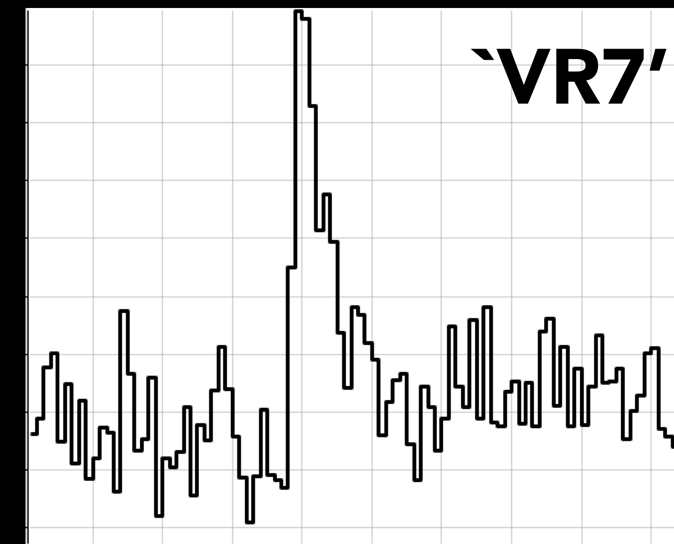
THE PROPERTIES OF LUMINOUS LAEs AT Z=6.6

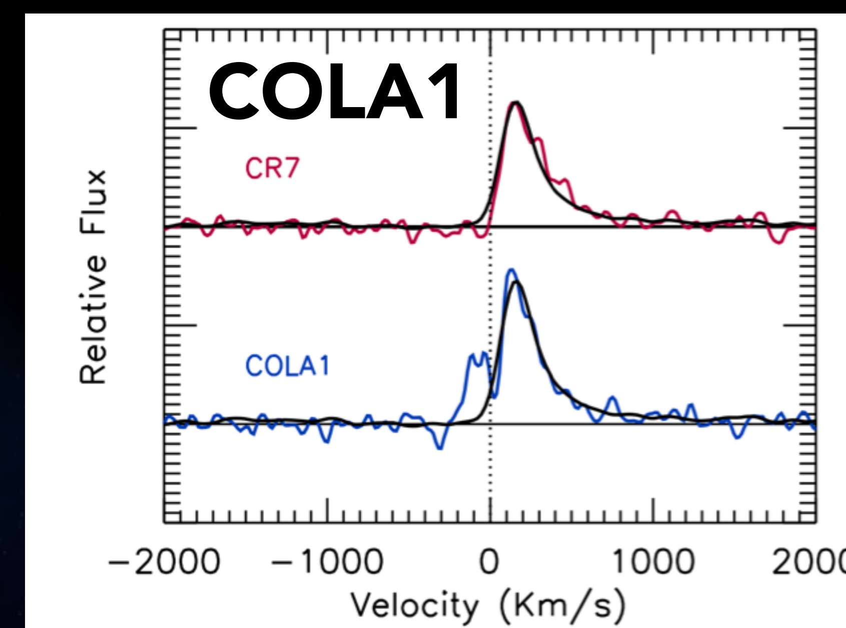


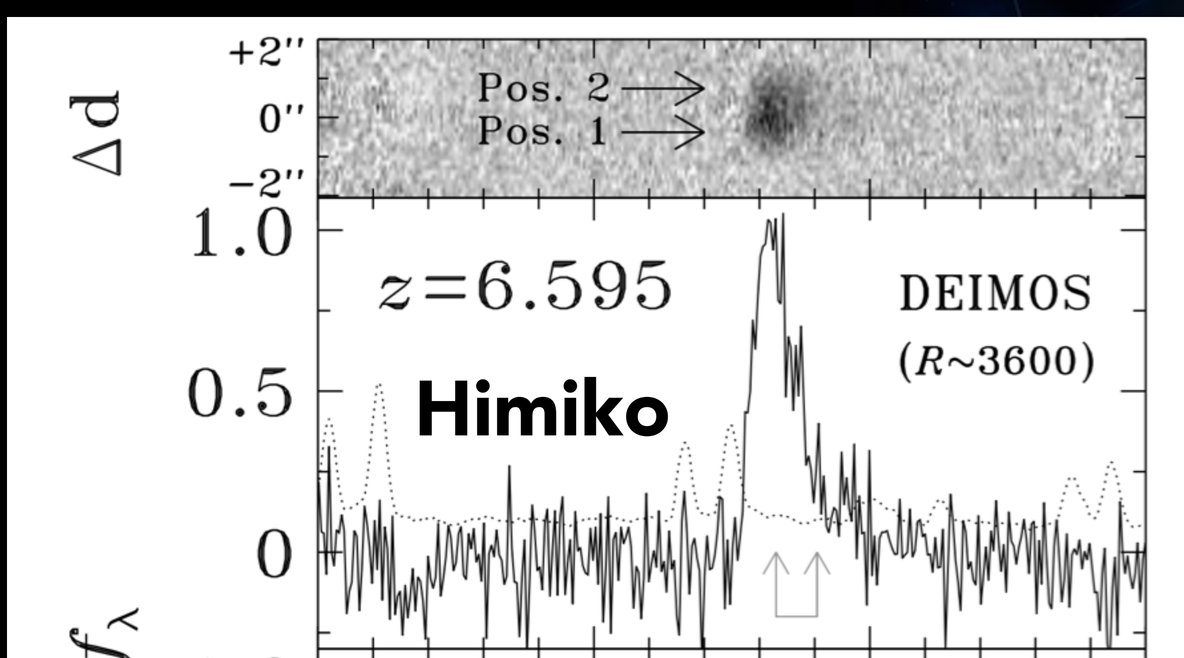
CR7 and the team of luminous z=6.6 LAEs











Himiko: Ouchi+2009,2013
CR7, MASOSA: Sobral+2015
COLA1: Hu+2016
VR7: Matthee+2015 & in prep

Sobral, Matthee et al. 2015 ApJ, 808, 139

THE NATURE OF LUMINOUS LAES

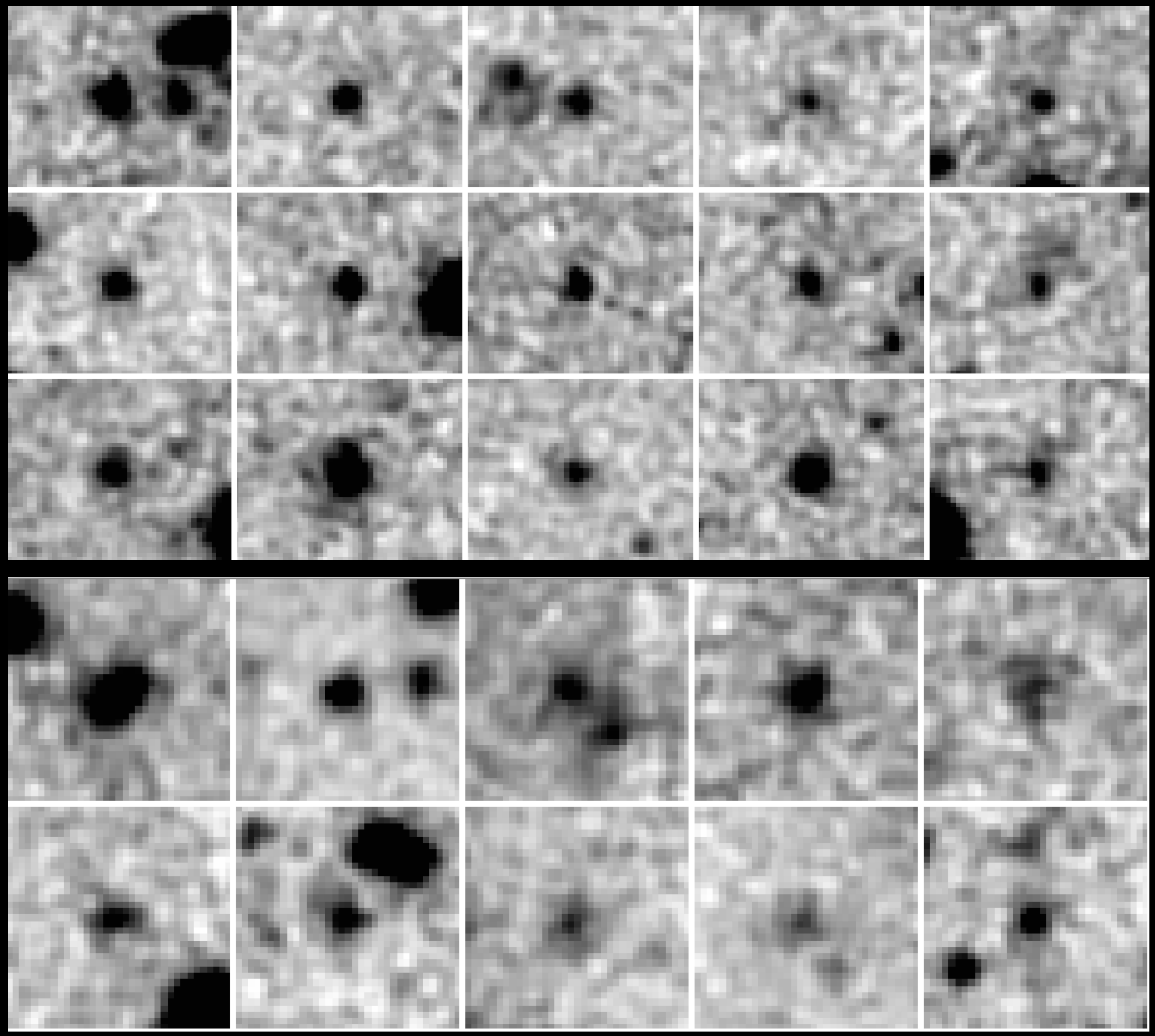
Luminous LAEs show a lot of diversity!

- Lya sizes

COSMOS >L* LAEs

NB816
z=5.7

NB921
z=6.6

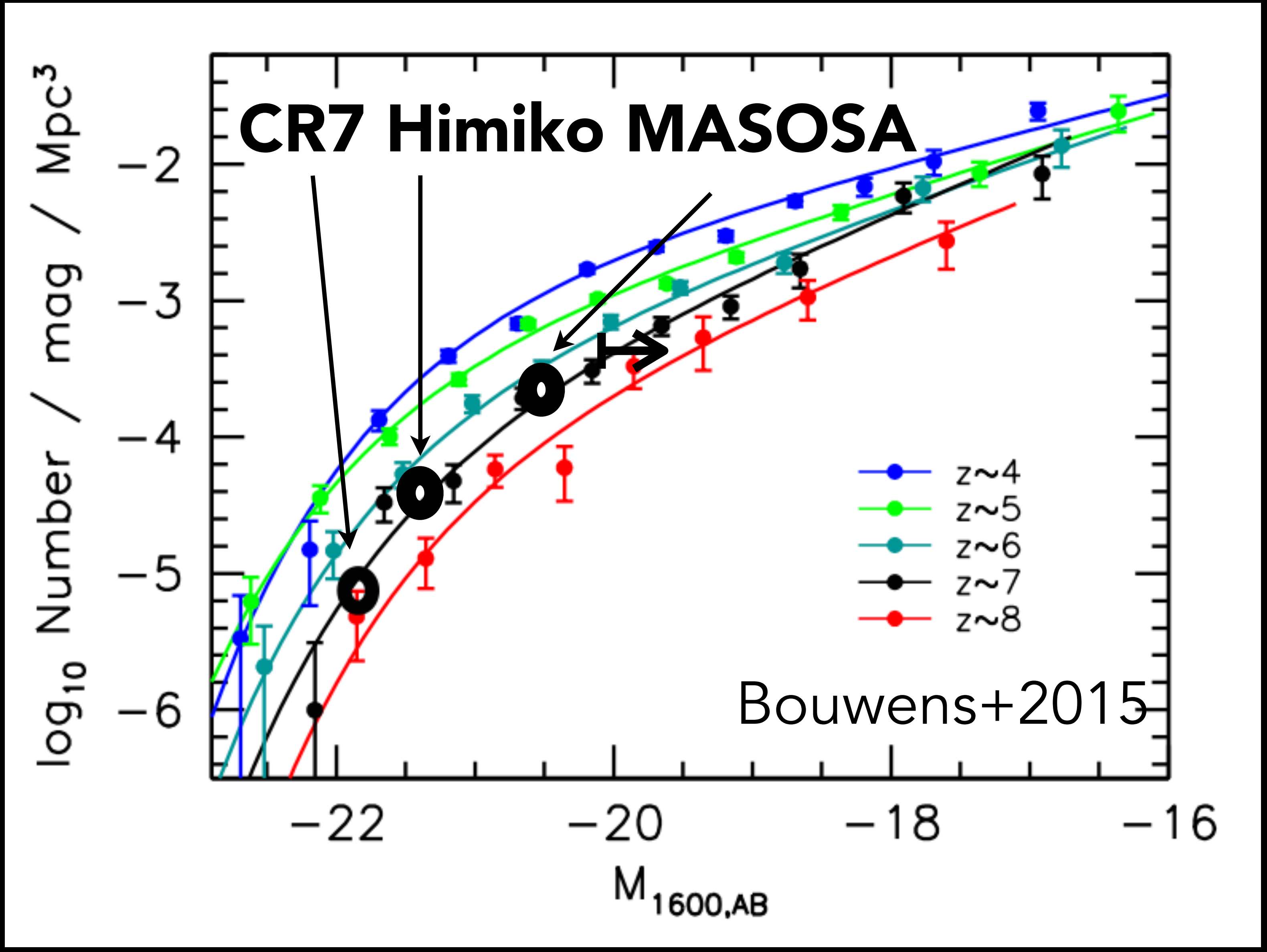


THE NATURE OF LUMINOUS LAES

Luminous LAEs show a lot of diversity!

- Lya sizes

- UV magnitudes



THE NATURE OF LUMINOUS LAES

Luminous LAEs show a lot of diversity!

- Lya sizes

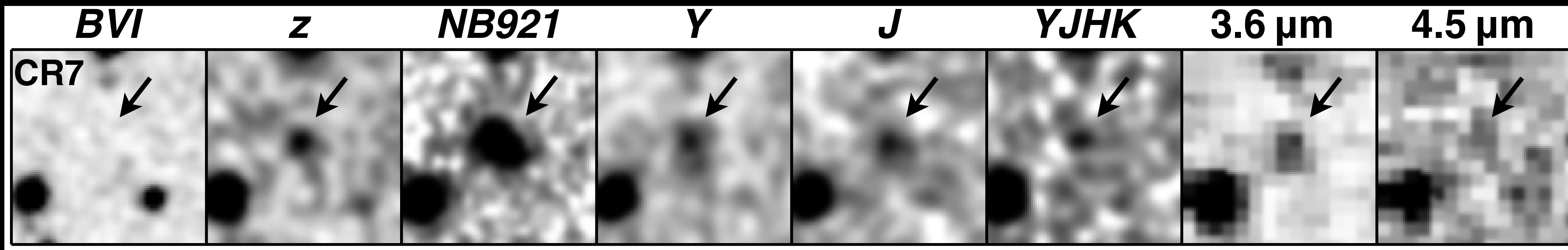
- UV magnitudes

- Lya FWHM

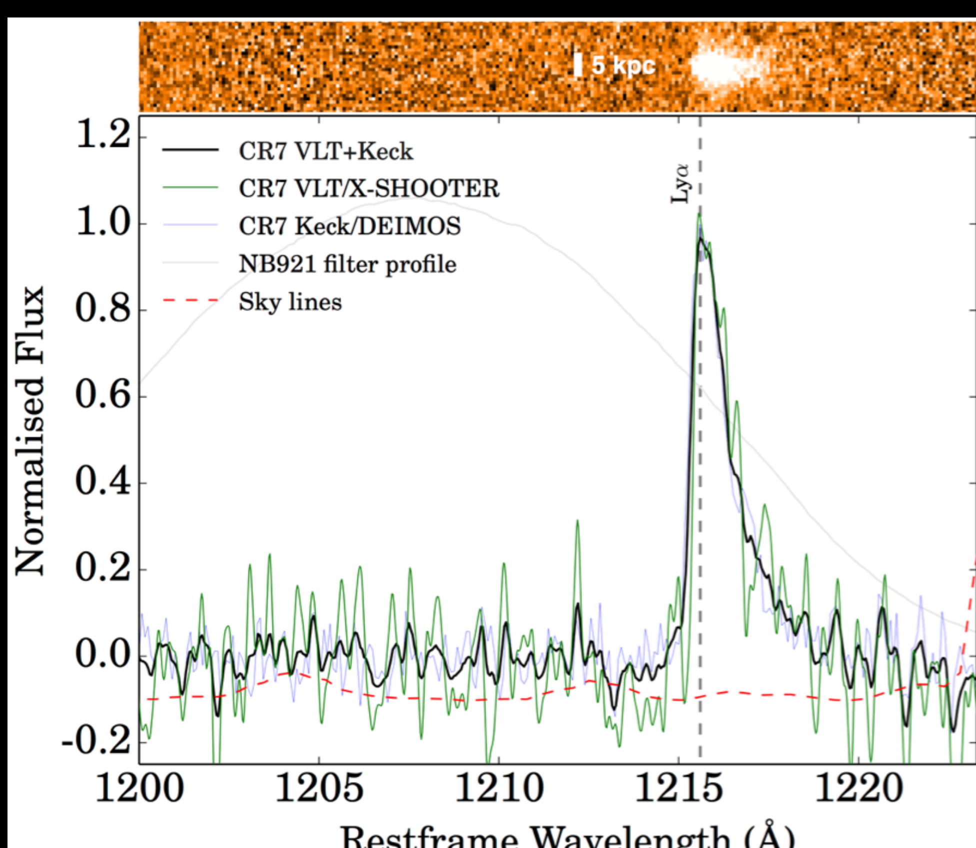
CR7: 266+-15 km/s
Himiko: 251+-21 km/s
MASOSA: 386+-30 km/s
COLA1: 194 km/s

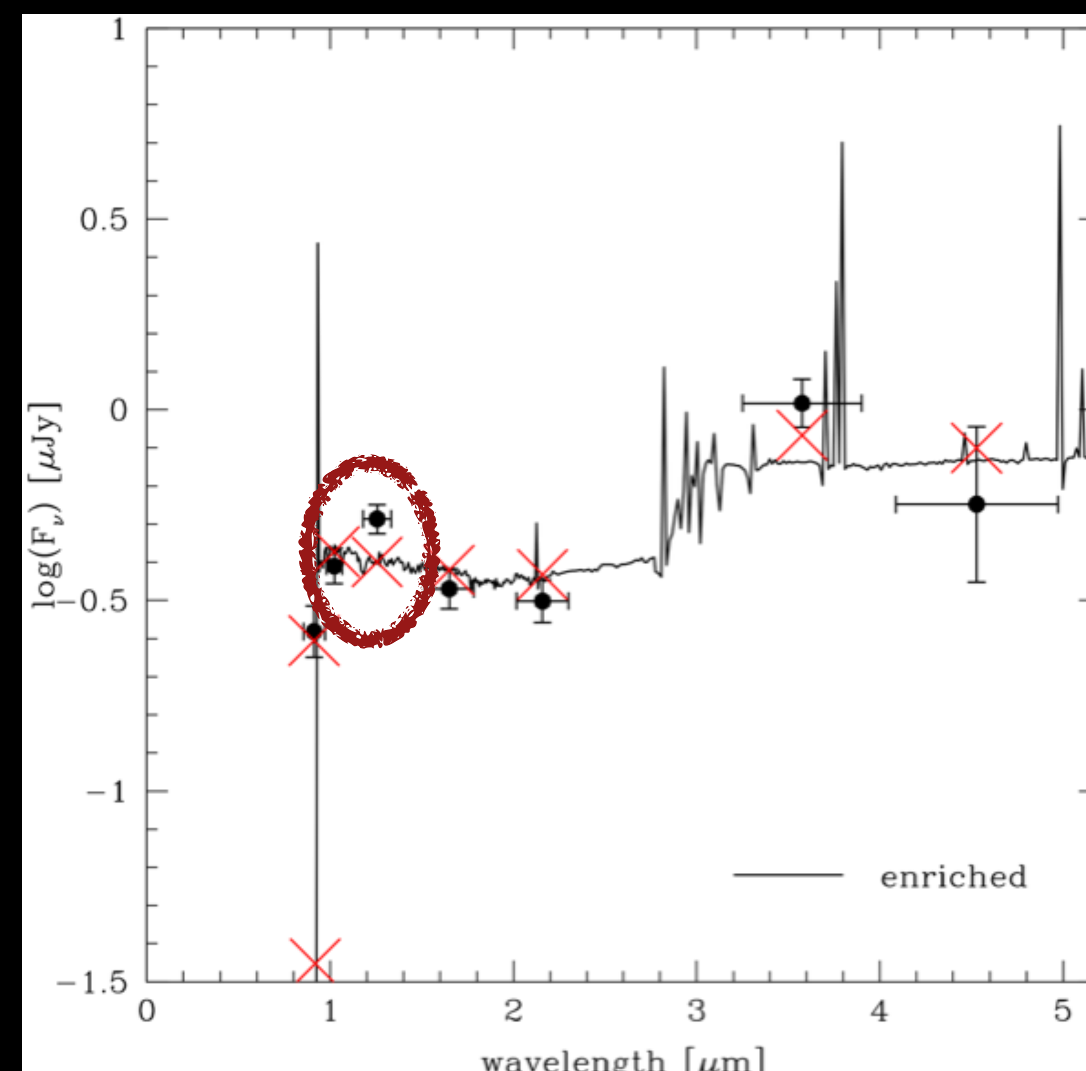
UV selected:
z=7.7 Oesch+2015: 360+-80 km/s
z=8.6 Zitrin+2015: 280+-220 km/s

Detailed properties of CR7

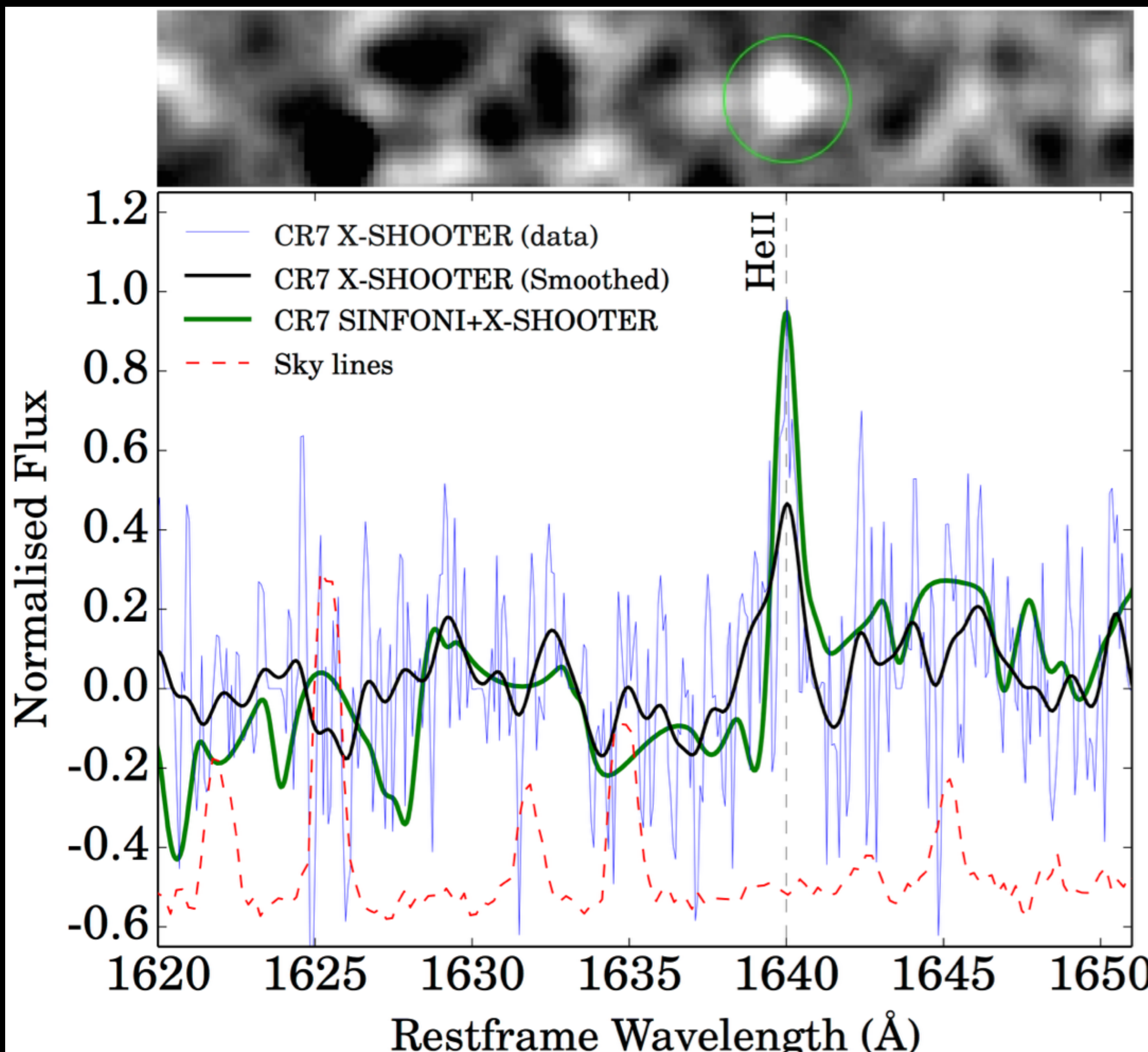


Selected as LAE, but already known in 2011 in Ilbert+ catalog and Bowler+2012 (but as brown dwarf/unreliable LBG z~6)





6 SIGMA HEII1640 EMISSION LINE

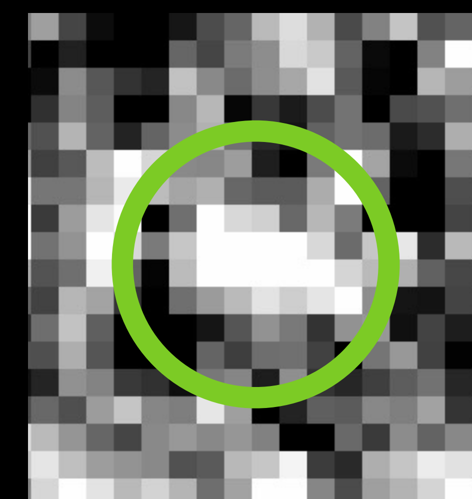


FWHM=130+-30 km/s

EW_0=80+-20 Å

HeII/Lya =0.23+-0.10

Velocity offset Lya-HeII 120km/s



Cassata+13 VUDS:

Typical HeII emitter z=3-5:

EW_0<7 Å

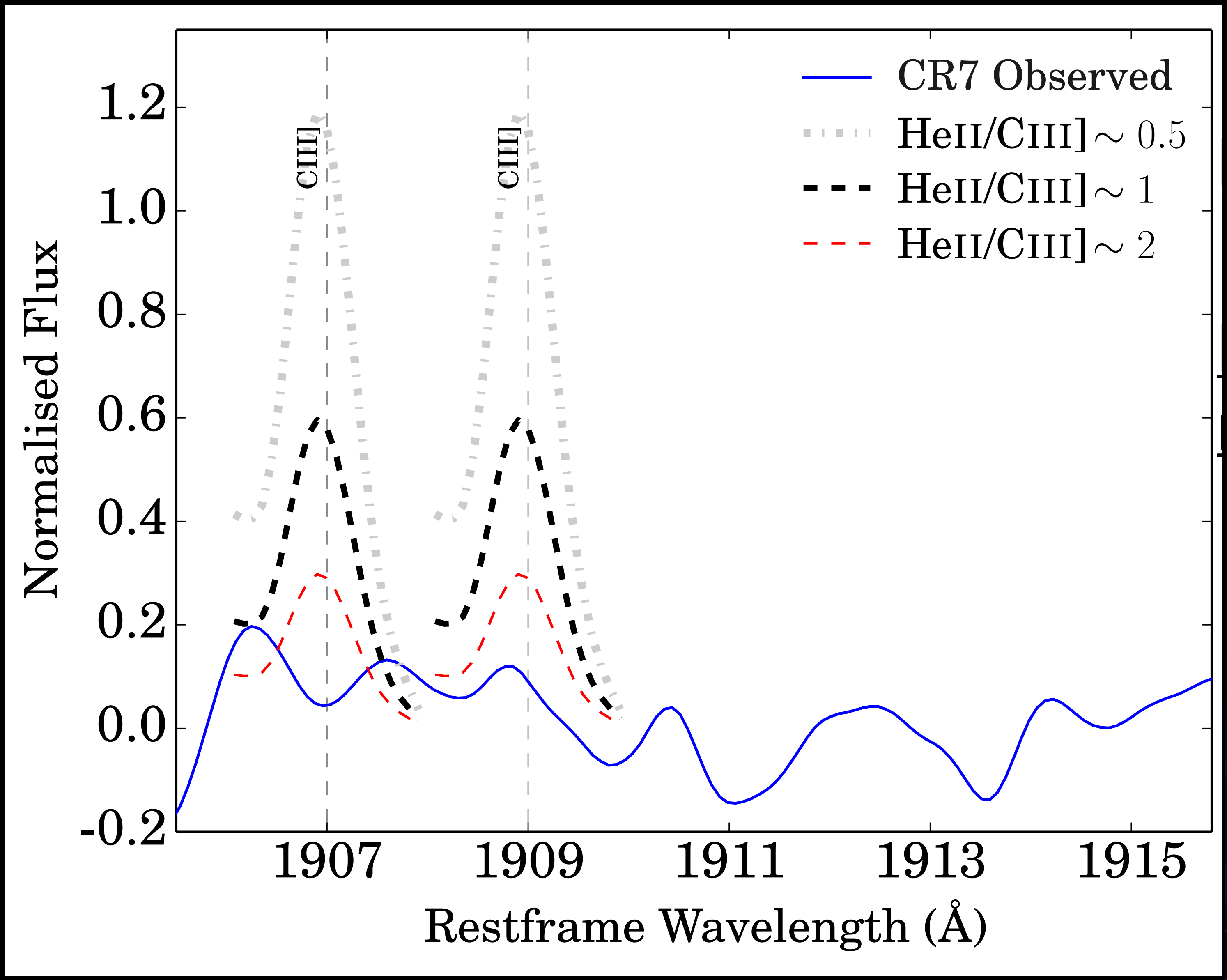
FWHM ~ 700km/s

> T_{eff} ~ 100,000K

Very hard ionising source: similar to other LBGs with CIII], CIV emission

Sobral, Matthee et al. 2015 ApJ, 808, 139

NO METAL EMISSION LINES



No NV, CIV, CIII], other high excitation metal lines

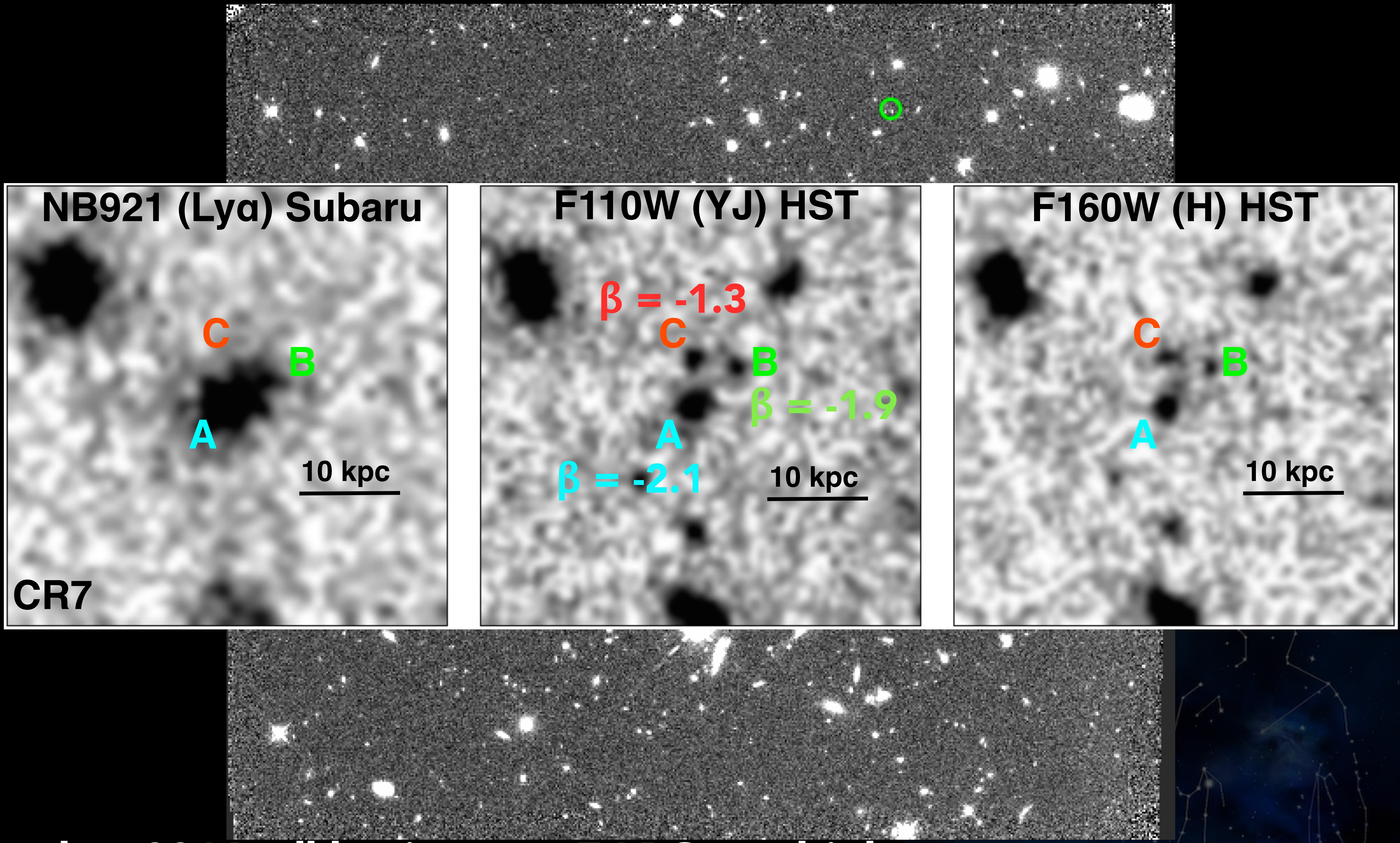
Lya/NV > 70
HeII/OIII] >3
HeII/CIII] > 2.5

Stark+2014, z~2:
Helium typically fainter!
HeII/CIII ~<0.5
HeII/OIII] ~<1-1.5

Metallicity must be *very* low: <1/200 Z_{sun}

Sobral, Matthee et al. 2015 ApJ, 808, 139

(ARCHIVAL) HST VIEW OF CR7

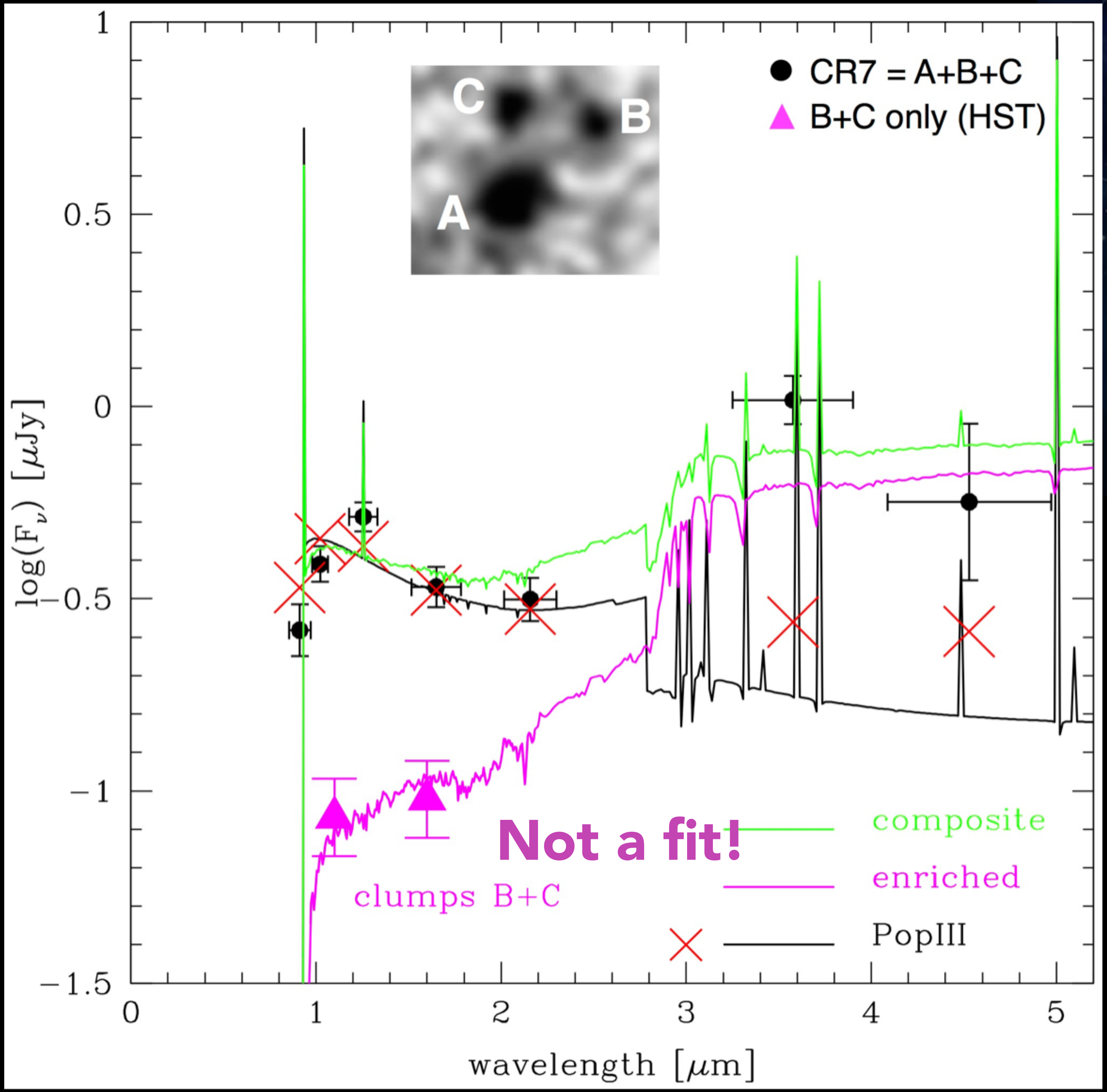


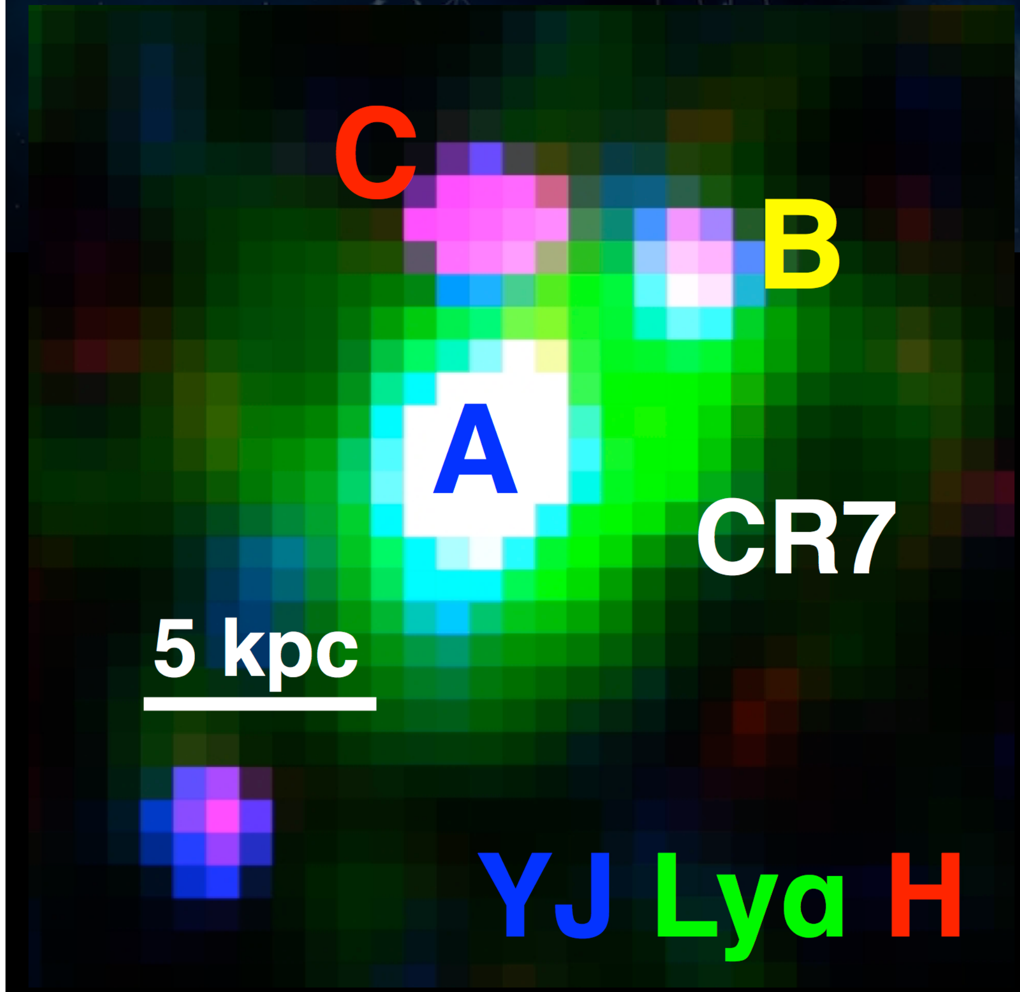
Bowler+2016: all luminous z~7 LBGs multiple components

Thanks Forster-Schreiber (PI HST data)!

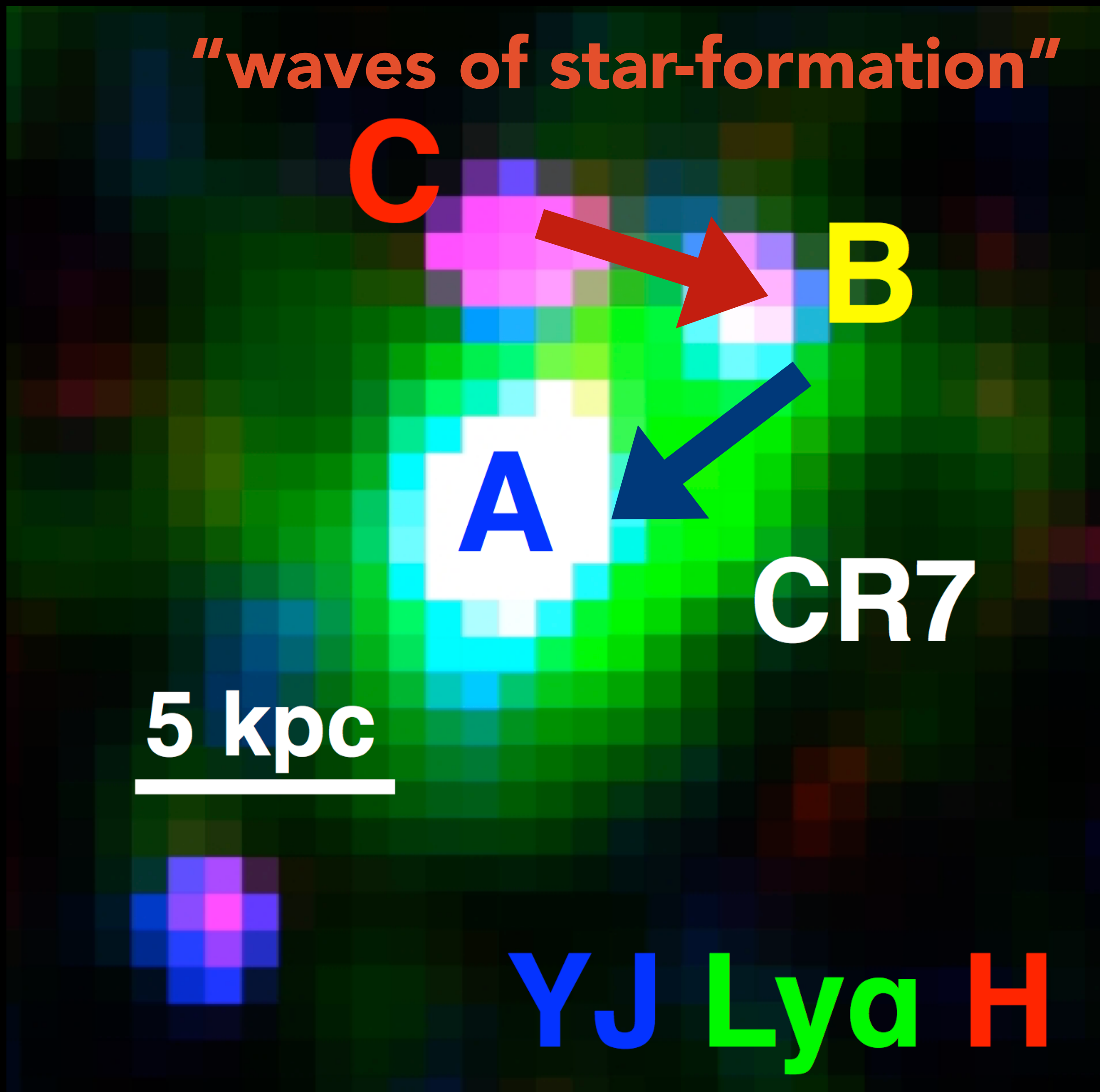
Sobral, Matthee et al. 2015 ApJ, 808, 139

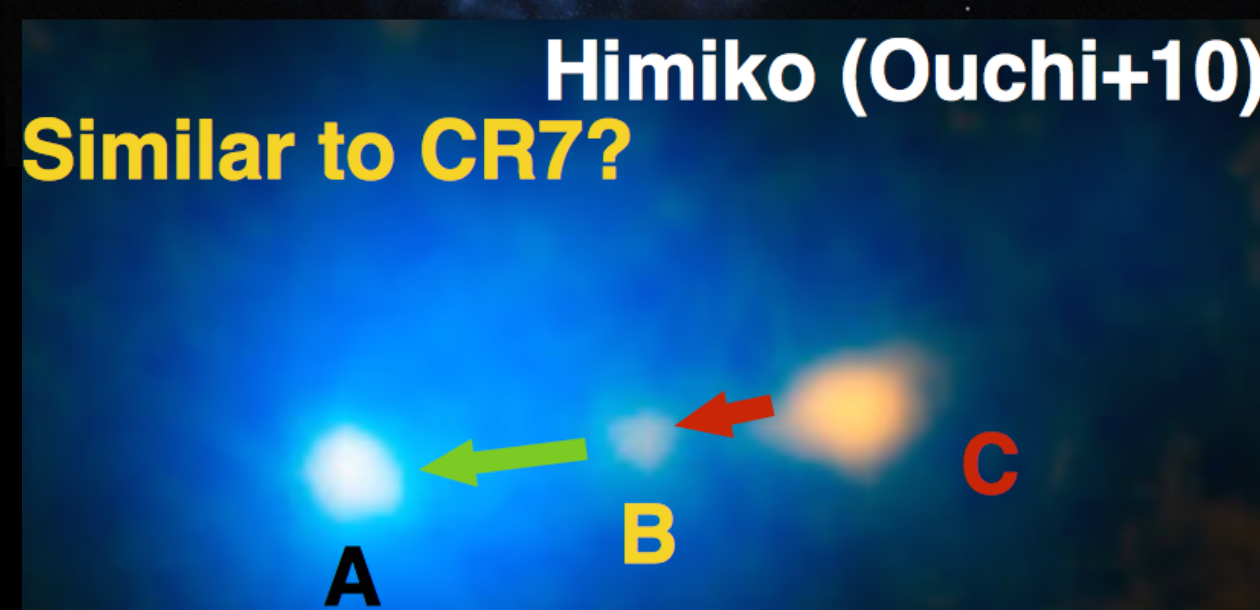
CURRENT DATA IS FULLY CONSISTENT WITH POPIII-*LIKE* CLUMP A+"NORMAL"STELLAR POP IN B+C





PopIII-like formation scenario:





Himiko: no HeII, nor metal lines: Zabl+2015

However, many theorists 'prefer' that CR7 is the first detection of a Direct Collapse Black Hole (DCBH)

The Brightest Lyα Emitter: Pop III or Black Hole?

Detecting Direct Collapse Black Holes: making the case for CR7

Exploring the nature of the Lyman-α emitter CR7

Evidence for a direct collapse black hole in the Lyman α source CR7

LYα SIGNATURES FROM DIRECT COLLAPSE BLACK HOLES

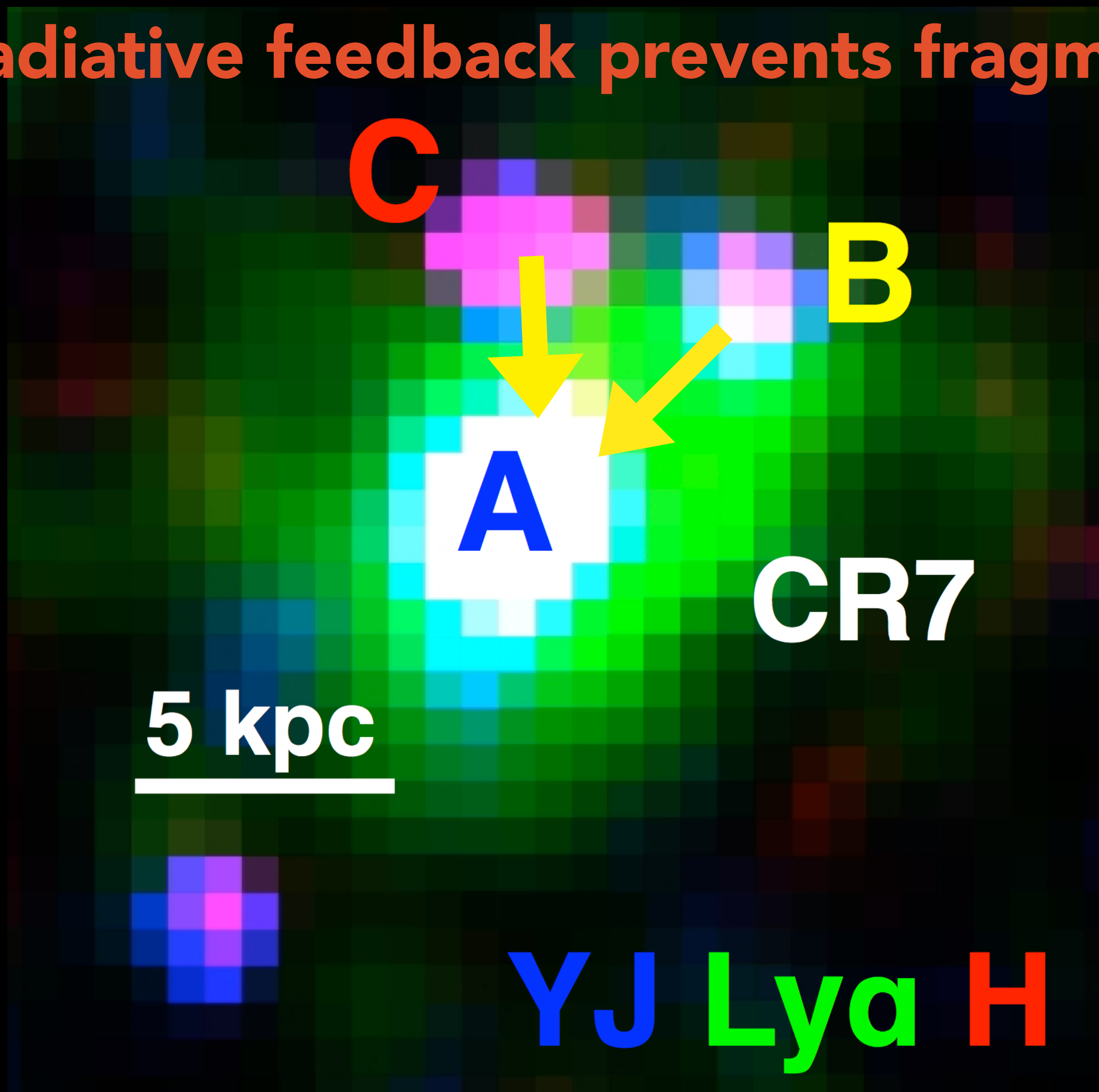
AB INITIO COSMOLOGICAL SIMULATIONS OF CR7 AS AN ACTIVE BLACK HOLE

Formation of Massive Population III Galaxies through Photoionization Feedback: A Possible Explanation for CR7

Pallotini+2015, Agarwal+2015, Hartwig+2015, Smith+2016, Dijkstra+2016, Smidt+2016
(but Visbal+2016 argue PopIII through similar mechanism) **see poster by Agarwal**

DCBH formation scenario:

Radiative feedback prevents fragmentation in clump A



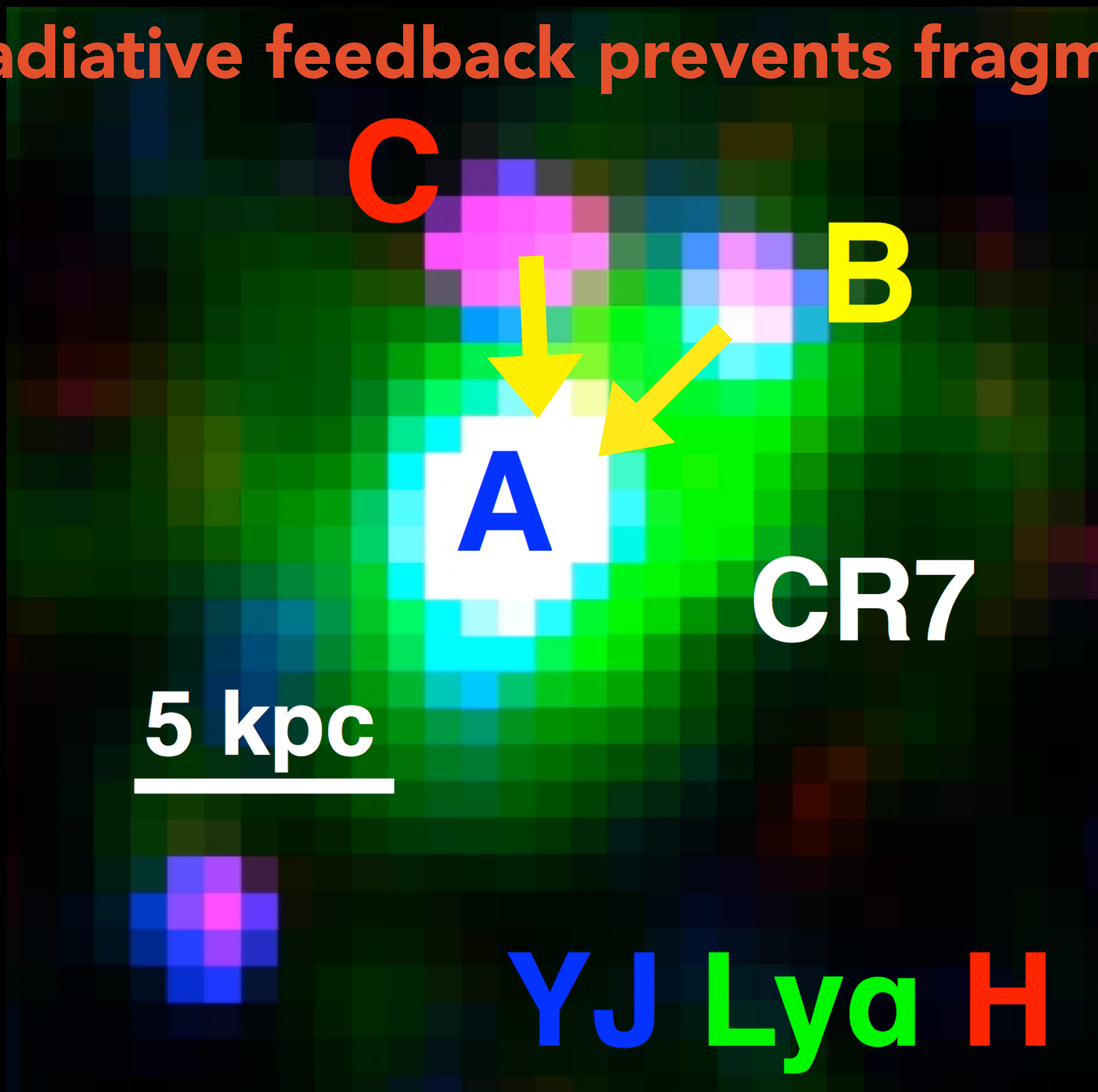
HST+Subaru image of CR7

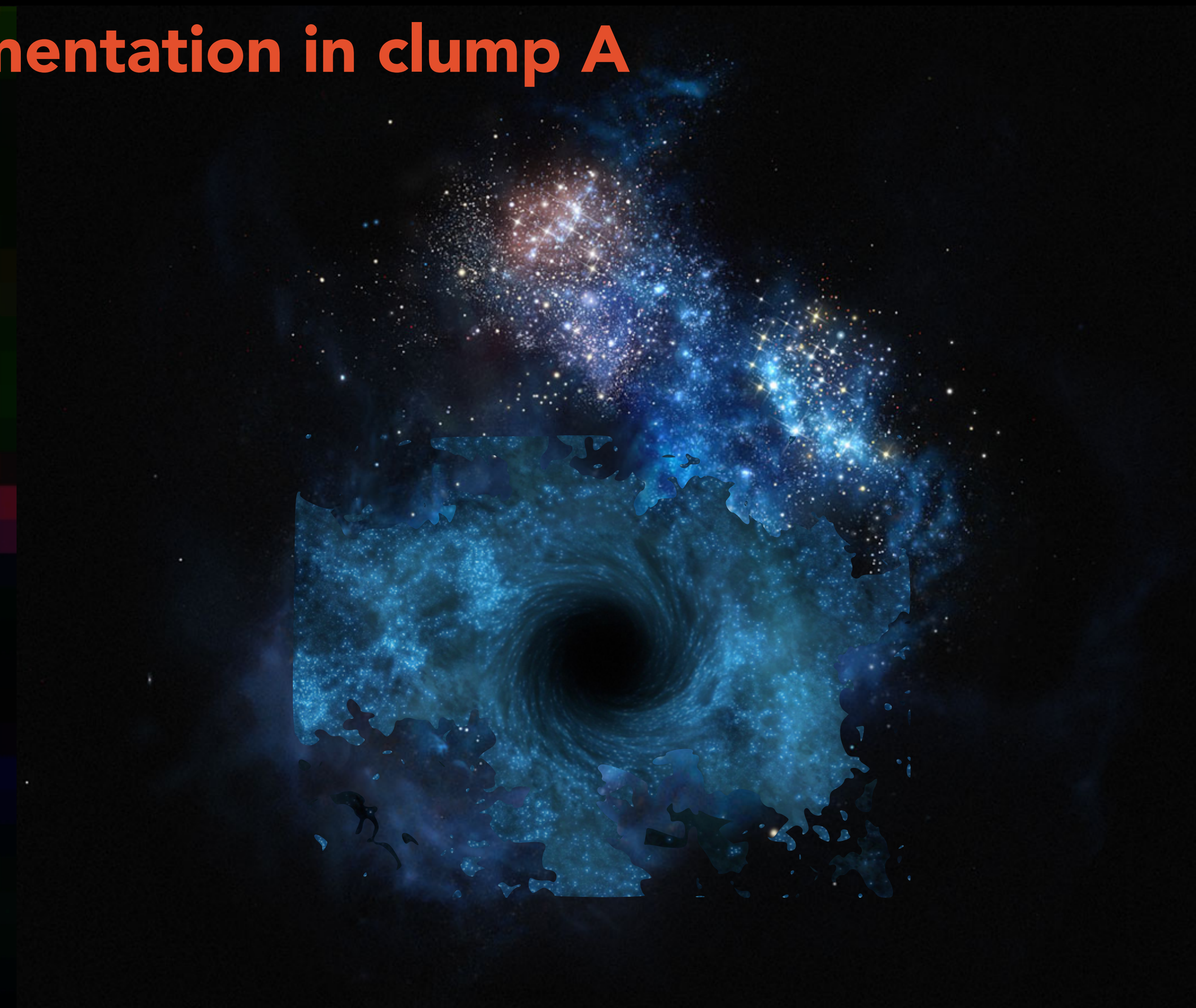
Artist impression (Kornmesser, ESO)

Pallotini+2015, Agarwal+2015, Hartwig+2015, Smith+2016, Dijkstra+2016, Smidt+2016
(but Visbal+2016 argue PopIII through similar mechanism) **see poster by Agarwal**

DCBH formation scenario:

Radiative feedback prevents fragmentation in clump A





HST+Subaru image of CR7

Artist impression (JM)

Pallotini+2015, Agarwal+2015, Hartwig+2015, Smith+2016, Dijkstra+2016, Smidt+2016
(but Visbal+2016 argue PopIII through similar mechanism)

see poster by Agarwal

Ongoing ALMA+HST follow-up: metallicity of hot and warm ISM

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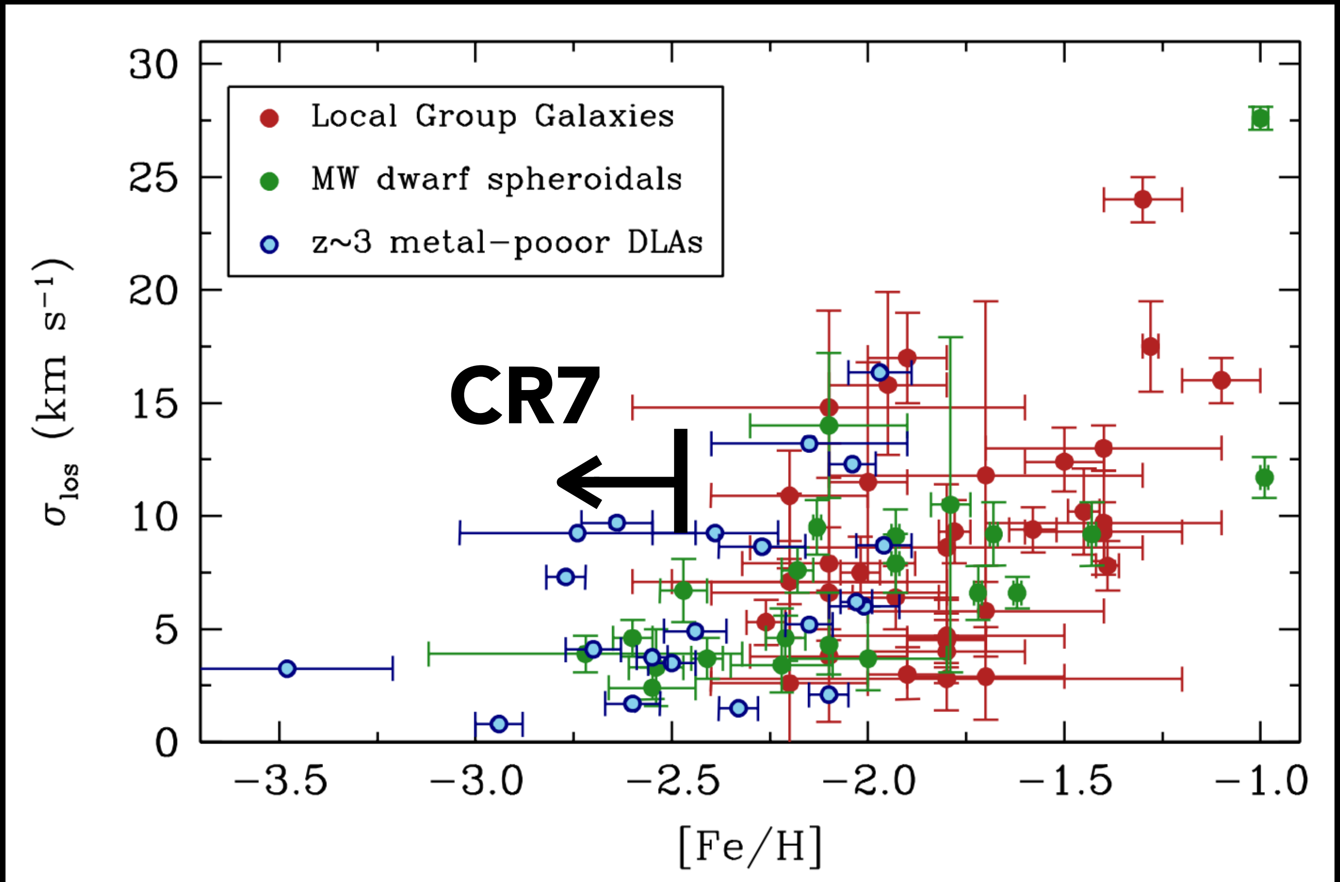
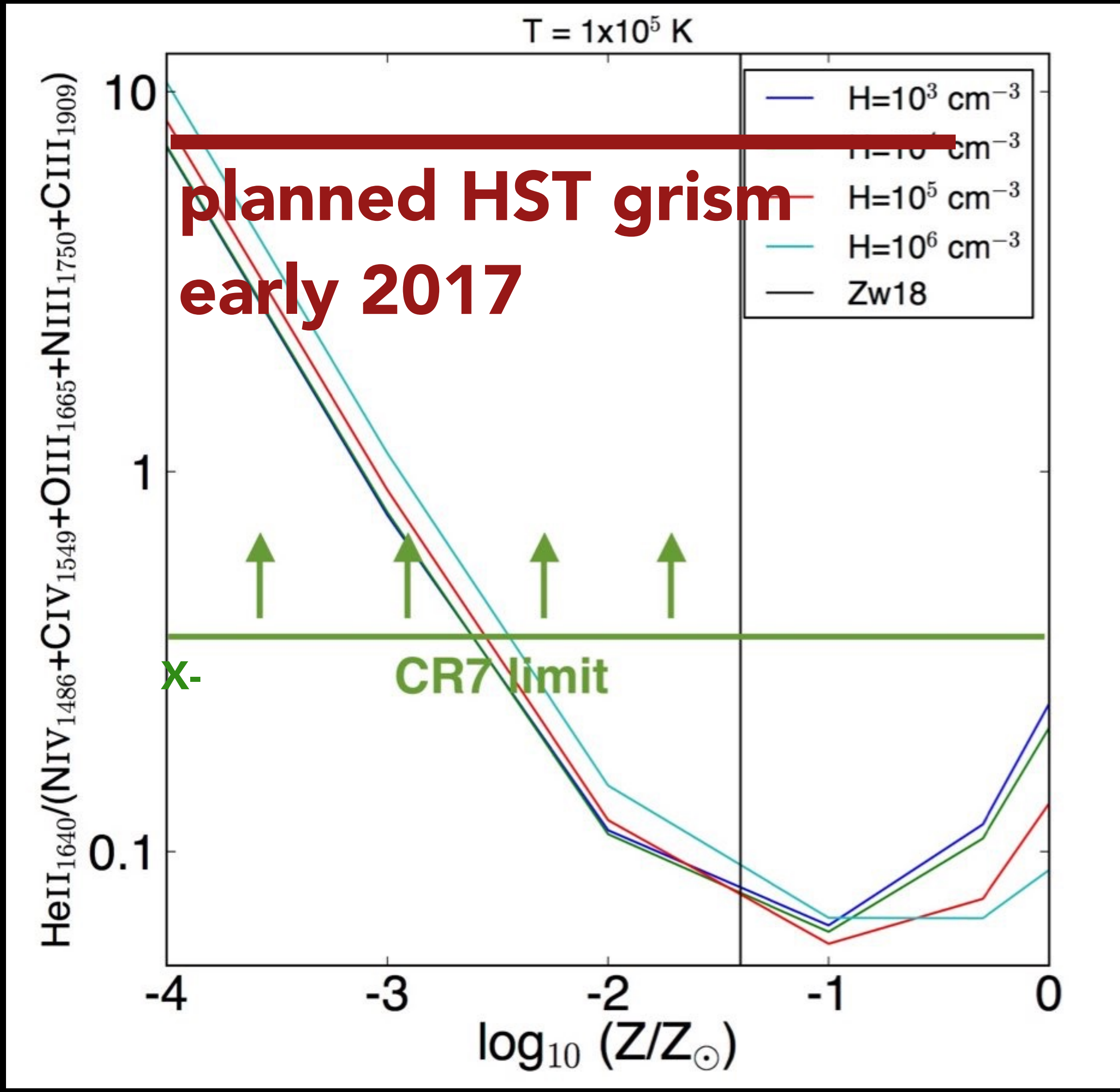
	2015.1.00122.S	CR7	10:00:58.01	+01:48:15.3	6	2600.64	In Progress
	2015.1.00122.S	CR7	10:00:58.01	+01:48:15.3	6	2600.64	In Progress
	2015.1.00122.S	CR7	10:00:58.01	+01:48:15.3	6	2600.64	In Progress

ALMA data almost available for [CII] & dust…

Ongoing ALMA+HST follow-up: metallicity of hot and warm ISM



CLOUDY modelling
blackbody, T=100,000K
(motivated from Lya-HeII)



Current constraint from X-SHOOTER: $Z/Z_{sun}<10^{-2.5}$

HST grism early 2017 will give $Z/Z_{sun}<10^{-4}$

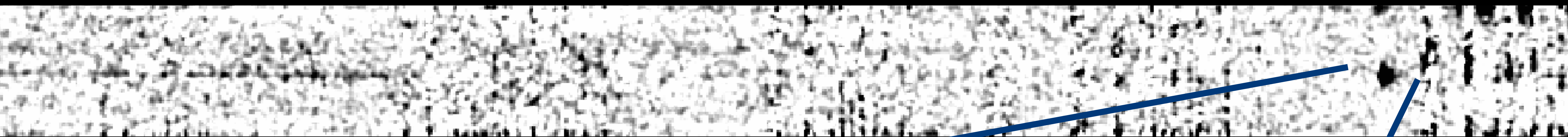
metal poor DLAs: Cooke, Pettini & Jorgensen 2015

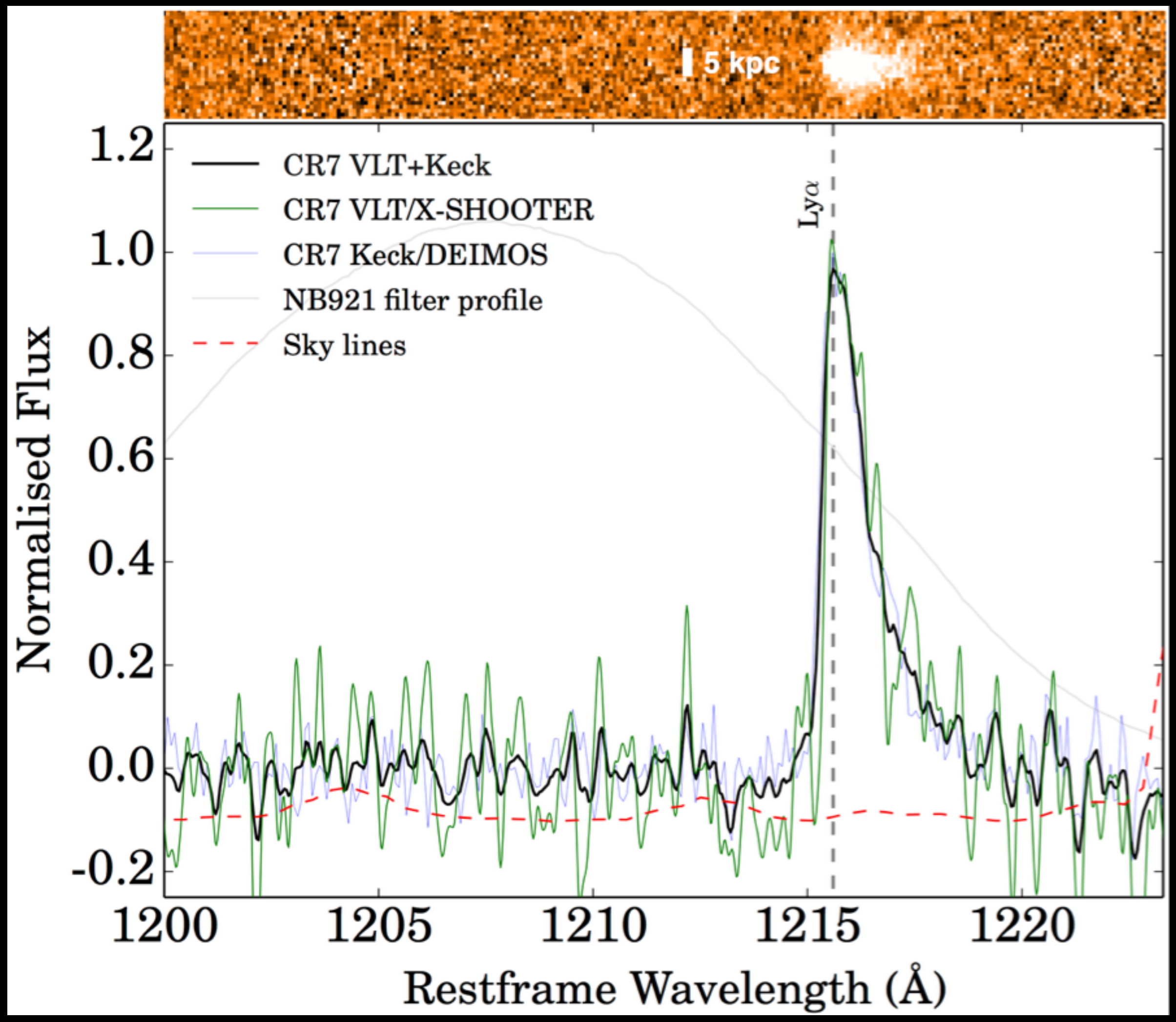
LYMAN-WERNER FLUX FROM CR7 ?

Escaping Lyman-Werner+ *hole* in the IGM?

Unseen in other z>6 galaxies
spatially coincident with peak Lya & HeII — very compact!

Lya





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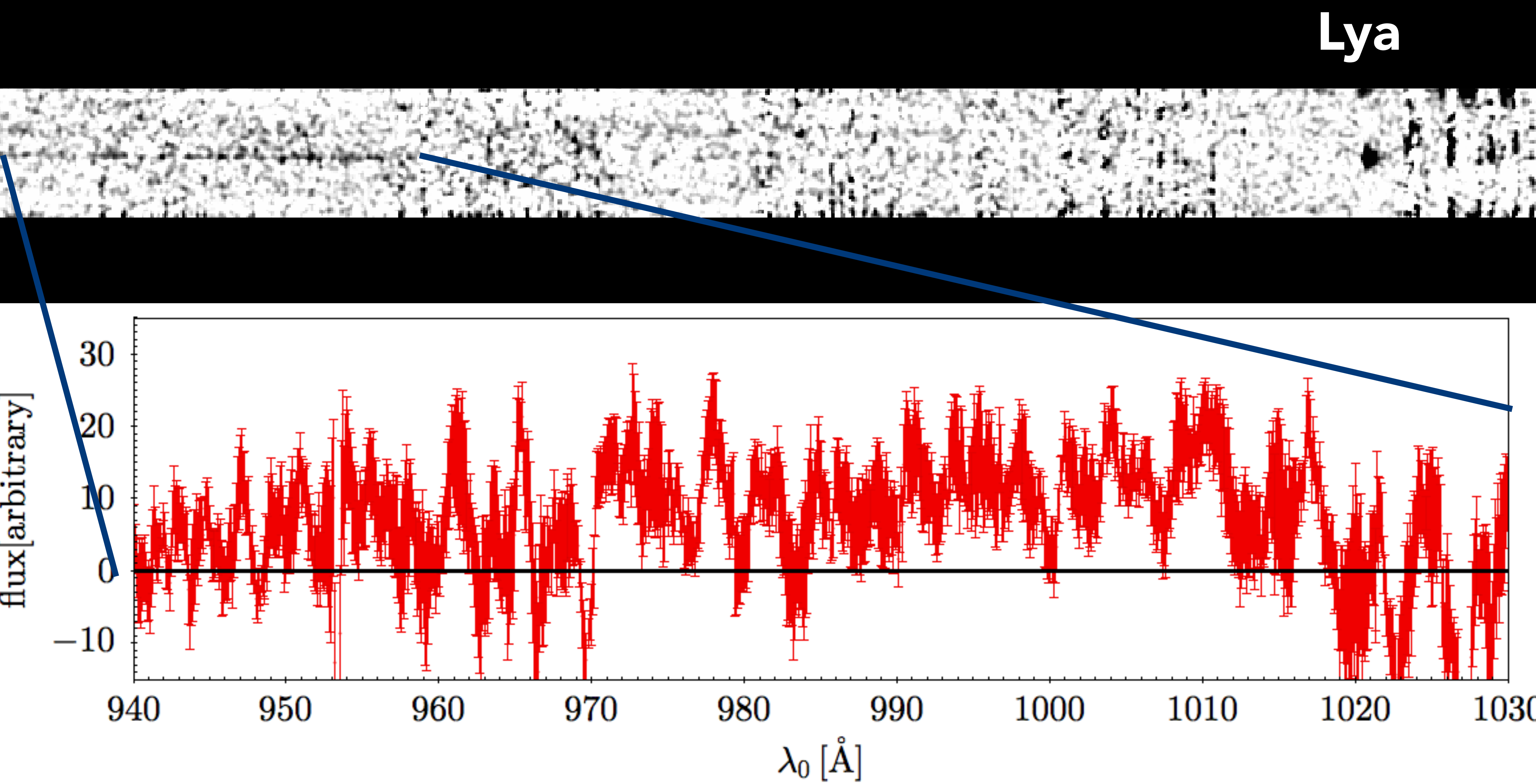
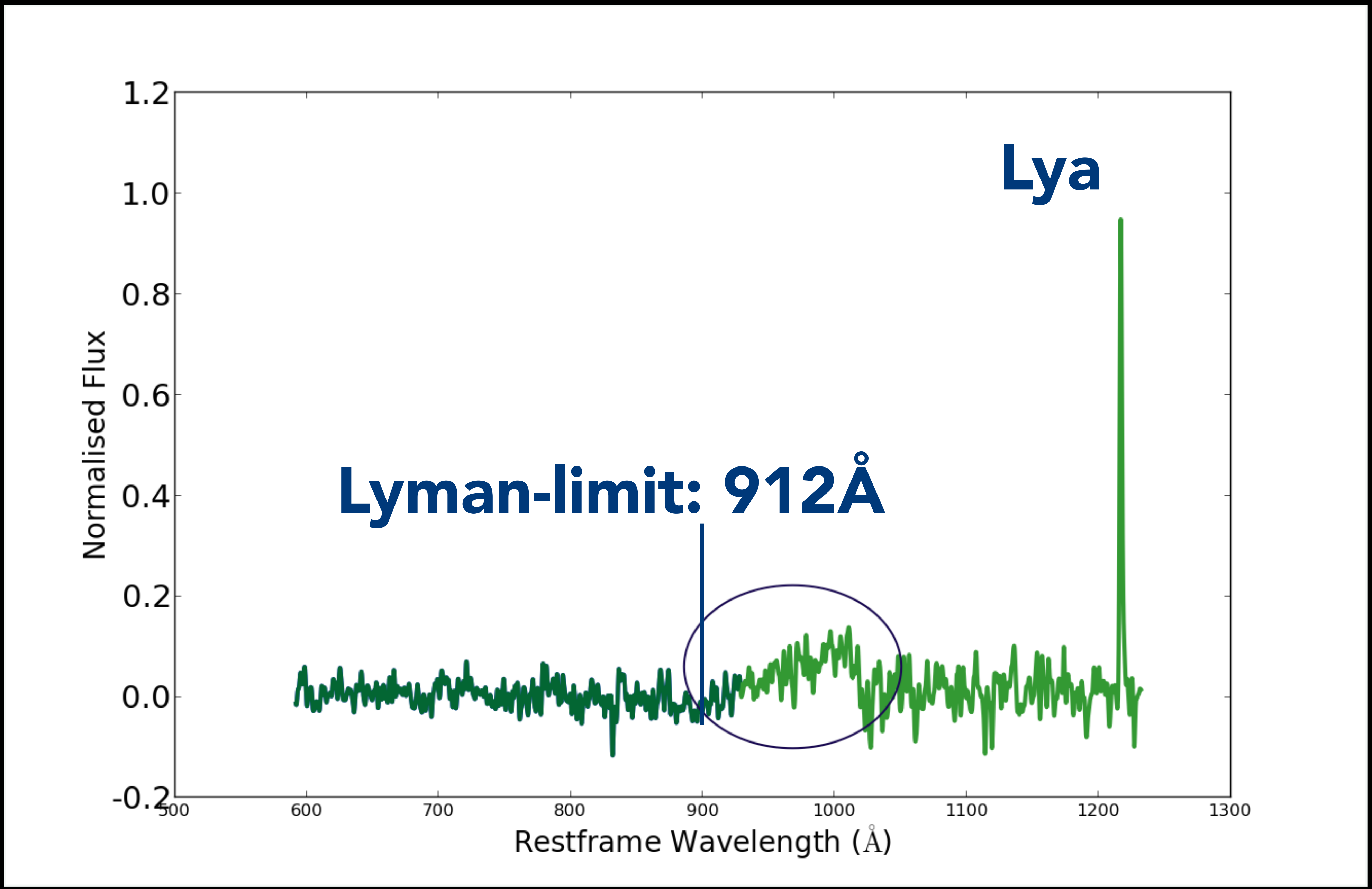


Matthee+2016 in prep.

LYMAN-WERNER FLUX FROM CR7 ?

Escaping Lyman-Werner+ *hole* in the IGM?

No flux observed below 912 Å



Matthee+2016 in prep.

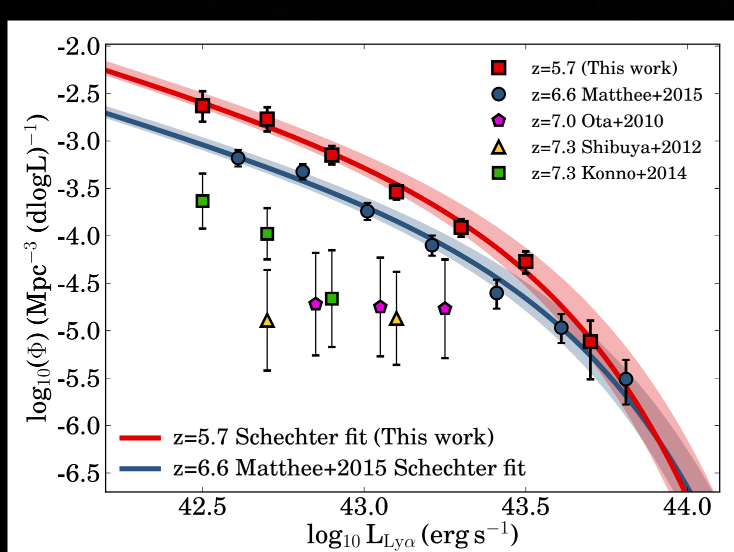
Matthee, Sobral et al. 2015 MNRAS 451, 4919
Sobral, Matthee et al. 2015 ApJ, 808, 139
Santos, Sobral & Matthee, 2016, arXiv: 1606.07435

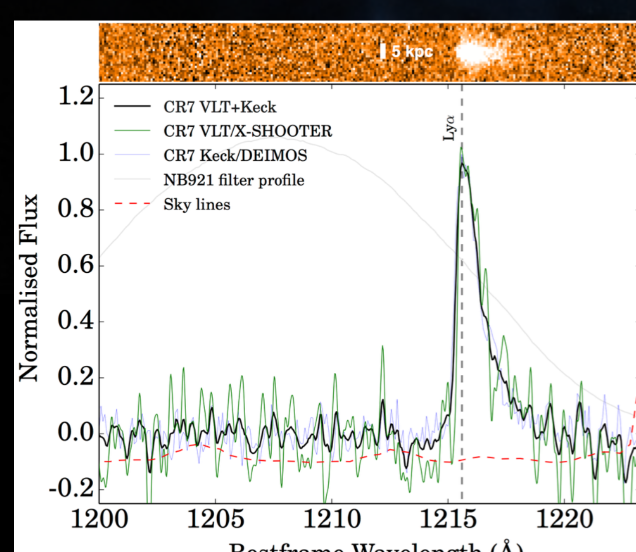
SUMMARY

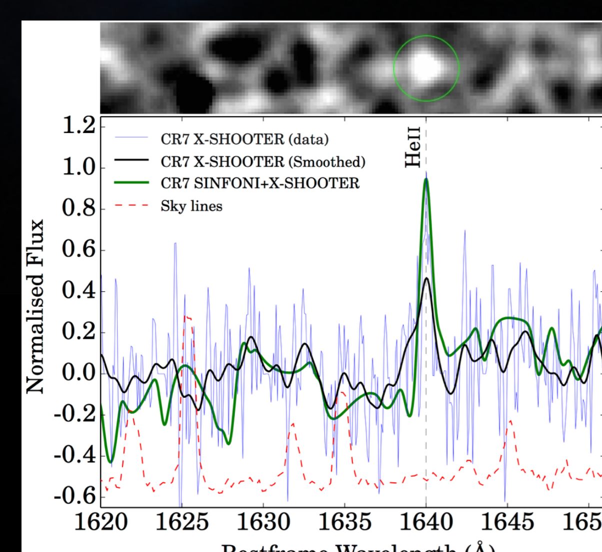
Faint LAEs are less abundant and more extended at z=6.6 than at z=5.7: patchy reionization?

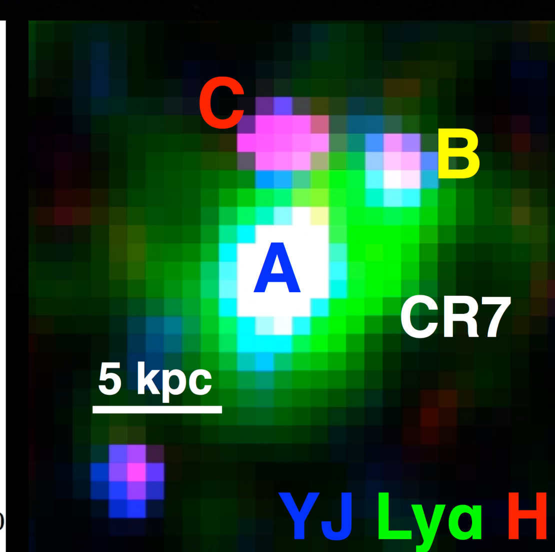
Bright LAEs show a surprisingly variety: compact vs extended Lya, multiple clumps, narrow FWHMs, blue peaks, Lyman-Werner.

COSMOS Redshift 7 hosts an extreme ionising source in low metallicity gas: PopIII stars or DCBH? Follow-up of CR7 and similar sources is ongoing.



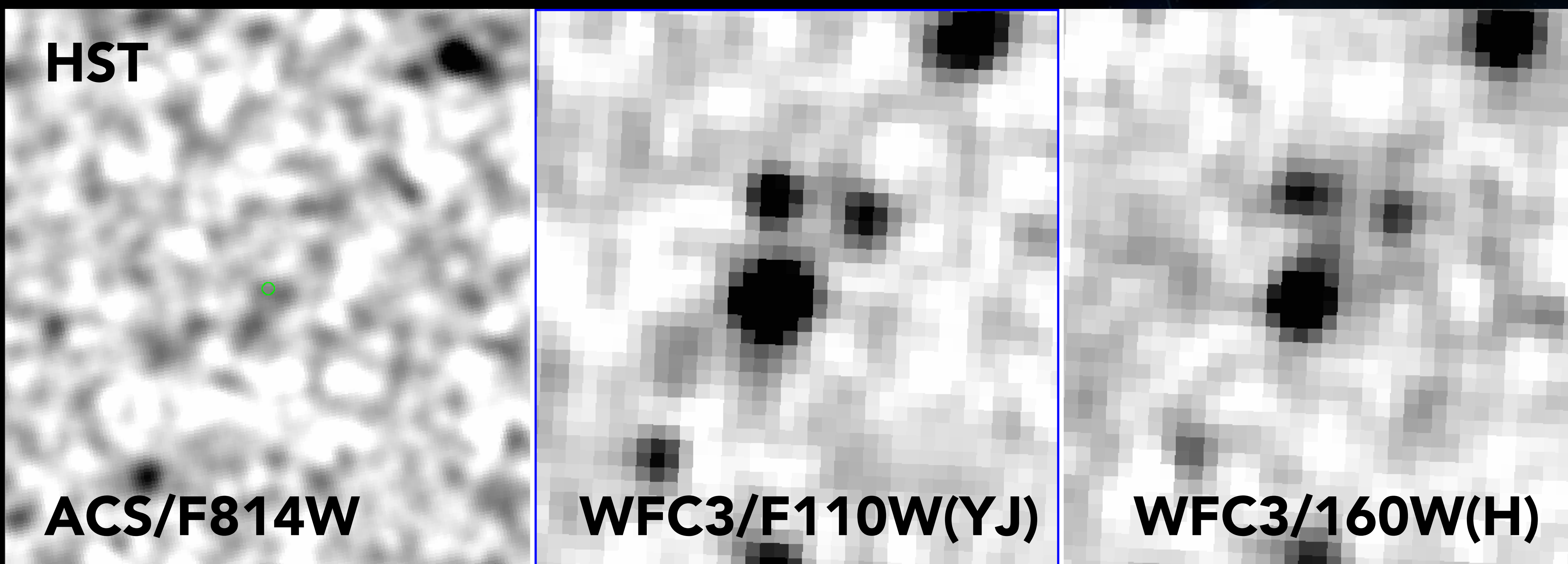






CLUMP B & C AT SAME REDSHIFT?

Clump B+C are not yet spectroscopically confirmed, but are z-dropouts, so photo-z>6.5 most likely

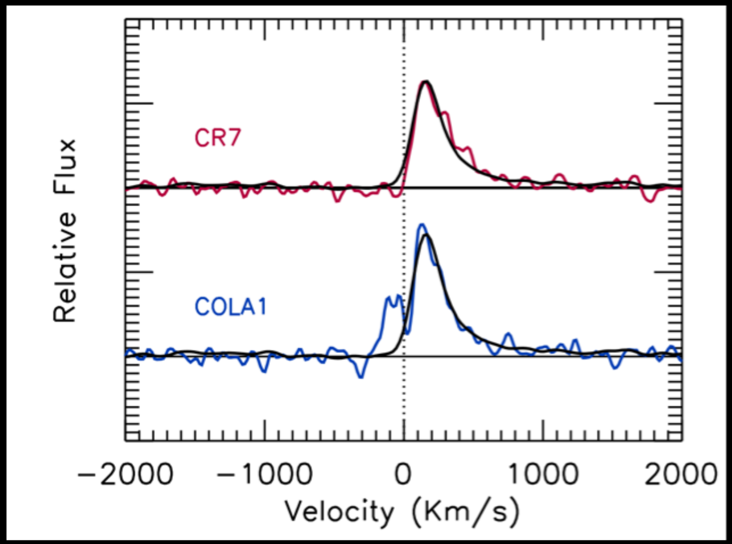


Sobral, Matthee et al. 2015 ApJ, 808, 139

Some (preliminary!!) indications that L_{Lya} scales with $f_{esc,LyC}$*Q_{ion}

Indirect signs of LyC escape from Lya line-profile (e.g. Verhamme+2015):

- low velocity offset Lya-HeII (CR7)
- blue peak Lya (COLA1)



From matched Lya-Ha survey z=2.2:

- ξ_{ion} (=Q_{ion}/L_{UV}) higher for LAEs than HAEs

LAE: $10^{25.14}$ Hz erg^{-1}; HAE: $10^{24.77}$ Hz erg^{-1}

- ξ_{ion} increases with EW(Ha), and thus increases with redshift

(Matthee+2016b,arXiv:1605.08782)