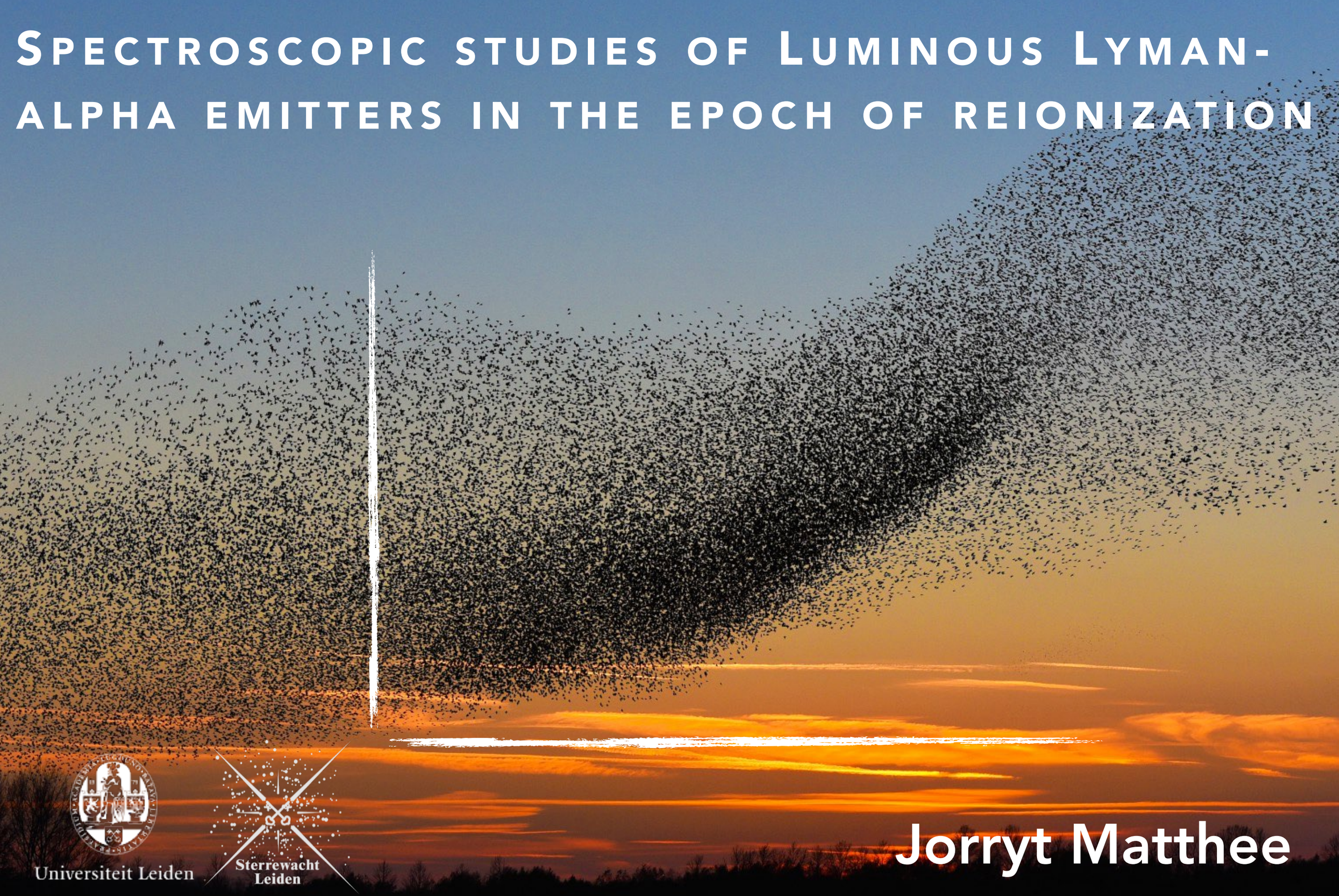
Spectroscopic studies of Luminous Lyman-alpha emitters in the epoch of reionization



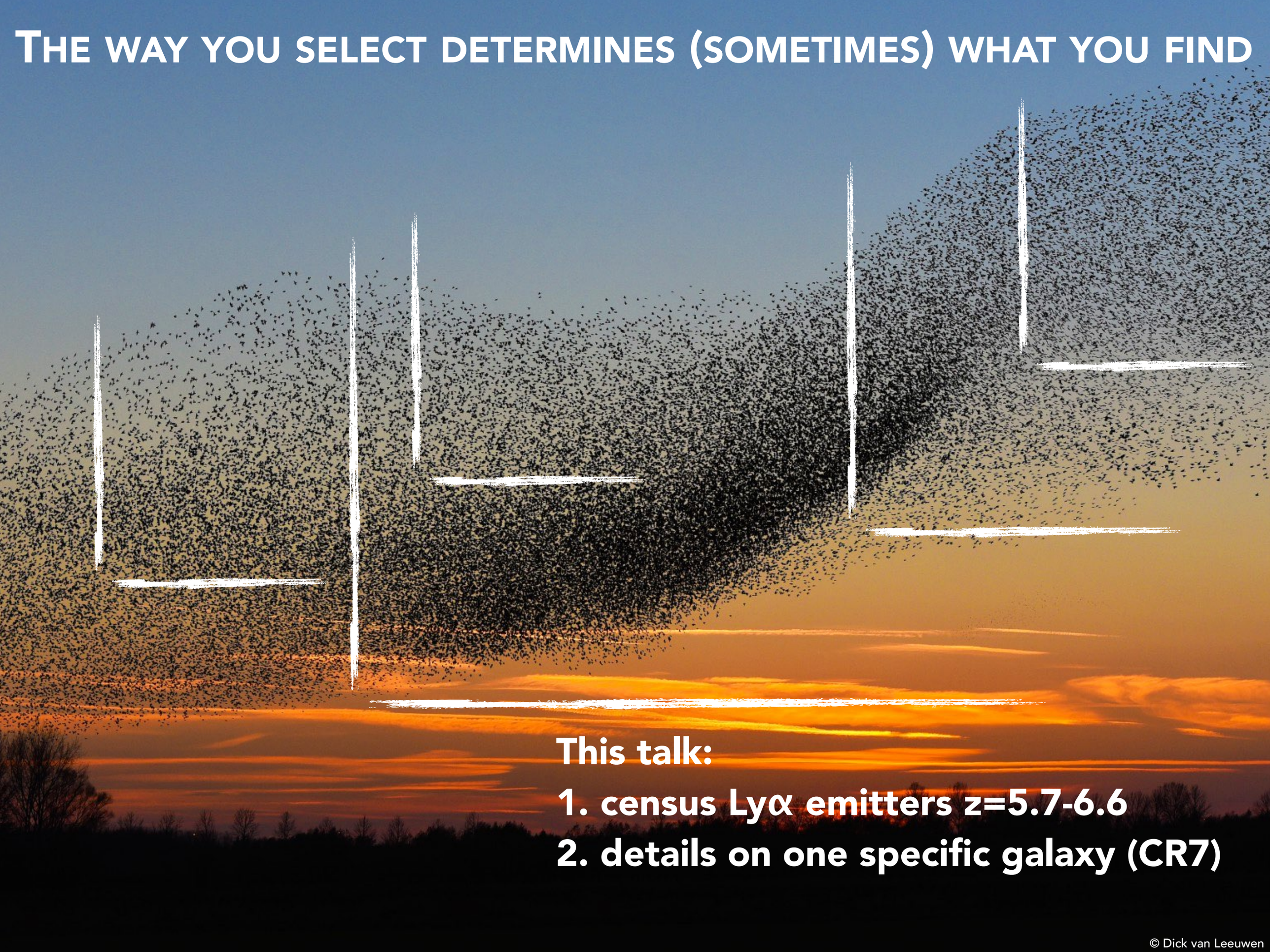
Universiteit Leiden

Sterrewacht Leiden

Jorryt Matthee

David Sobral, Huub Röttgering, Sérgio Santos, Behnam Darvish, **Daniel Schaerer**, Frédéric Boone, **Andrea Pallottini**, **Andrea Ferrara**, Bahram Mobasher, Livia Vallini, Marianne Girard

The way you select determines (sometimes) what you find

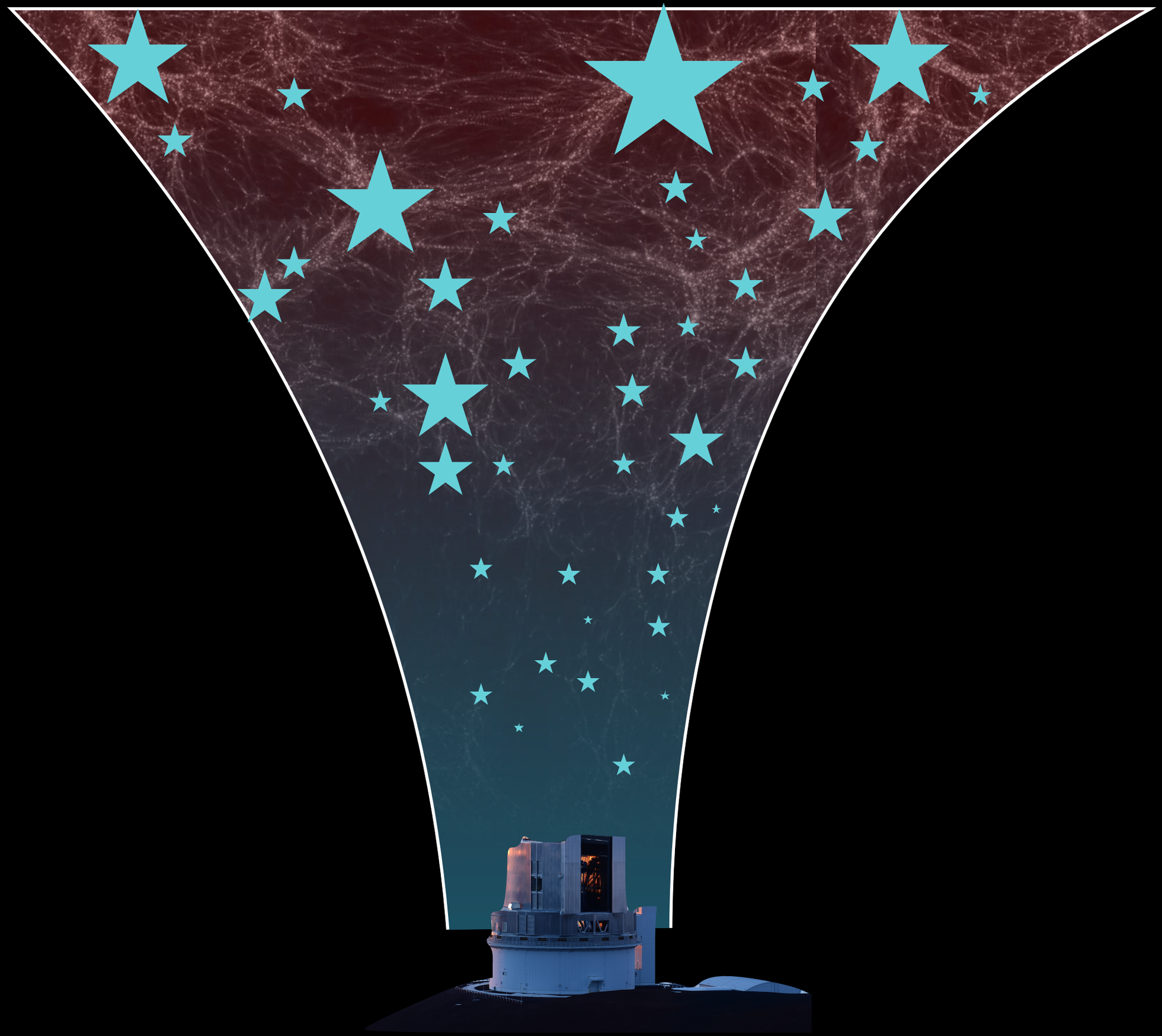


This talk:

1. census Lyα emitters z=5.7-6.6

2. details on one specific galaxy (CR7)

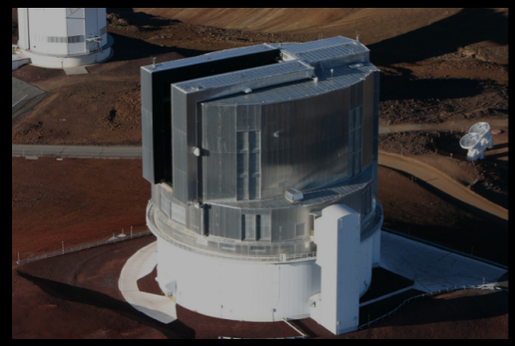
Two complementary strategies to find distant galaxies

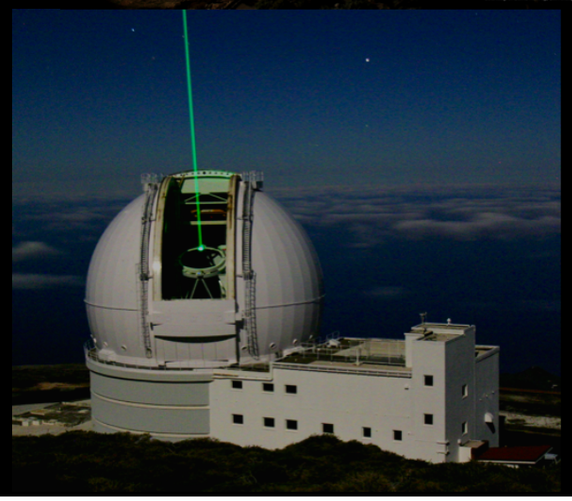


Our very wide field coverage

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

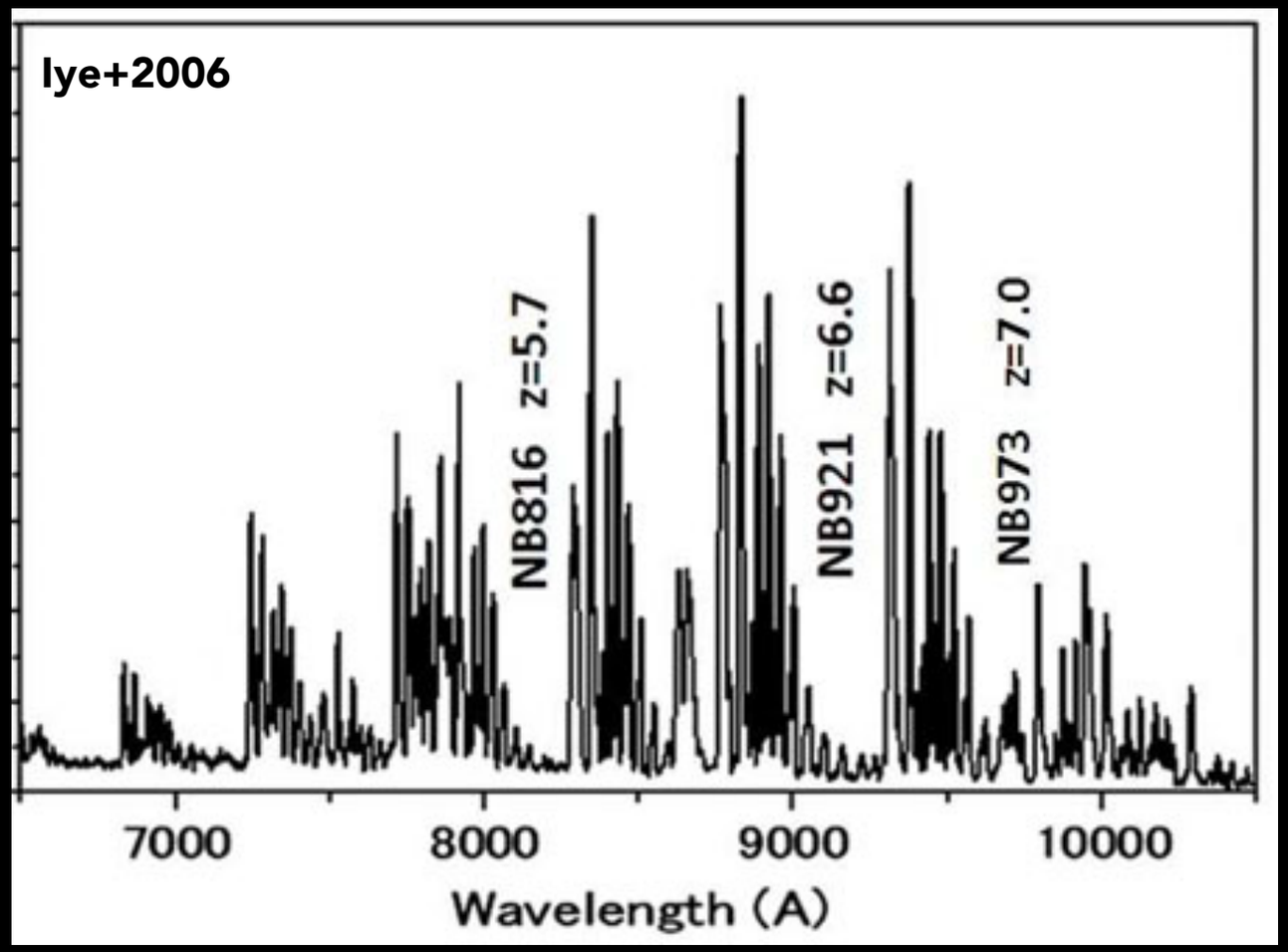
Full CANDELS

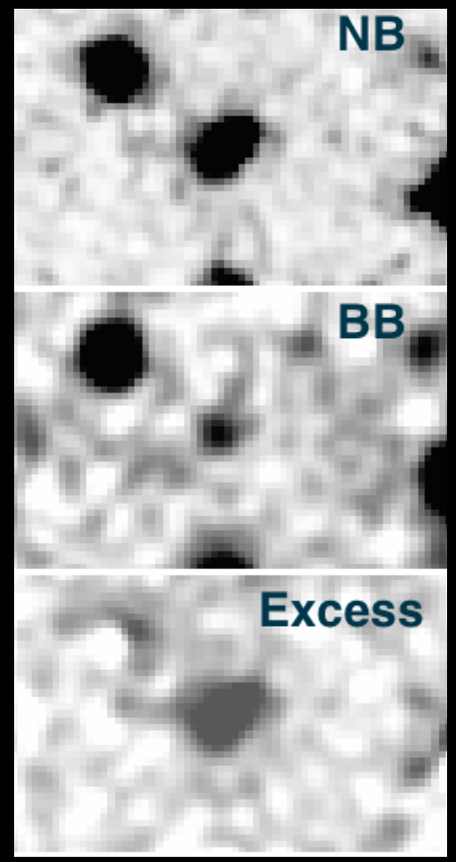




Matthee et al. 2015, 2017c; Santos, Sobral & Matthee 2016; Sobral et al. 2017a

NARROW-BAND TECHNIQUE

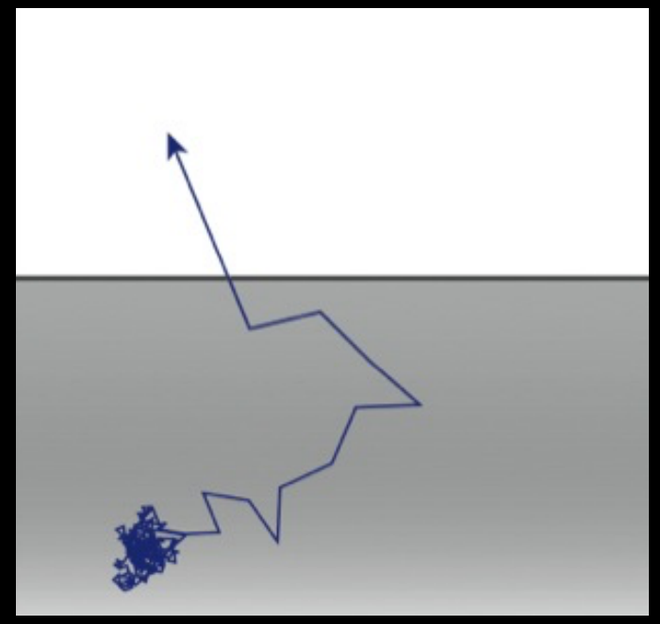




Efficiently select the Lyman-α (1216Å) emission-line at z=5.7, 6.6

e.g. Ouchi+2008,2010; Konno+2014,2017; Matthee+2014,2015, Nilsson+2007; Malhotra & Rhoads 2000,2004; Hayes+2010, Santos +2016, Shibuya+2017, Zheng+2017

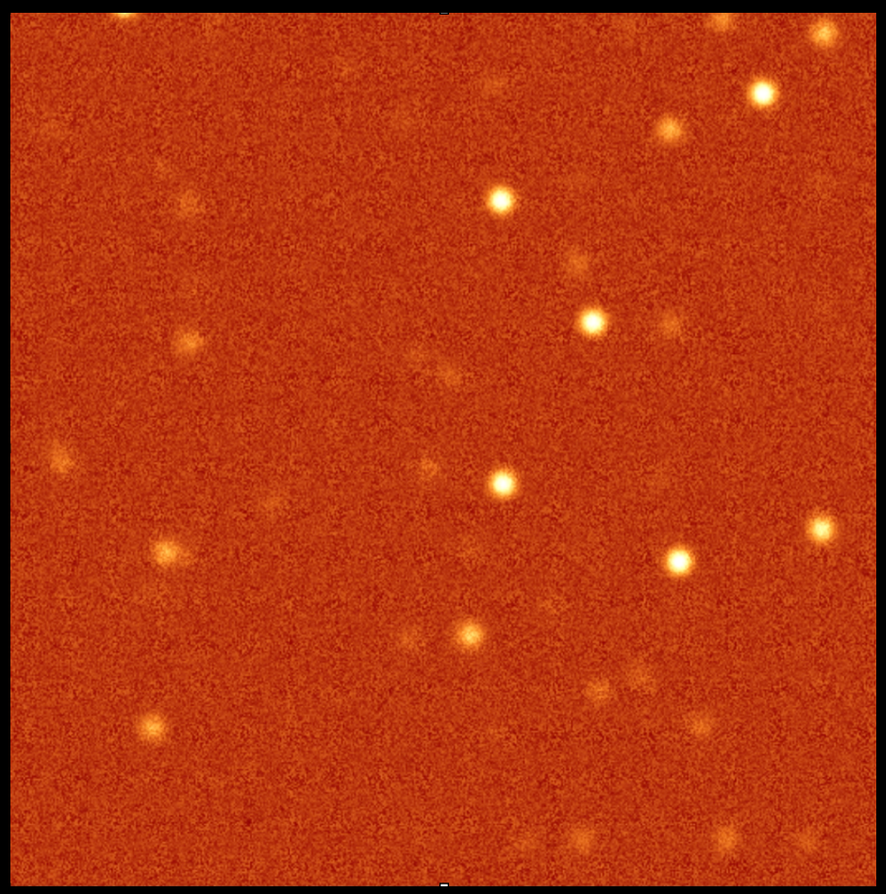
WHY LYMAN-ALPHA?

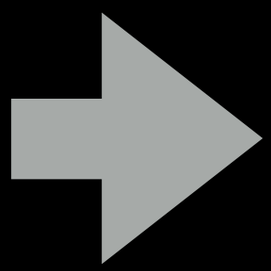


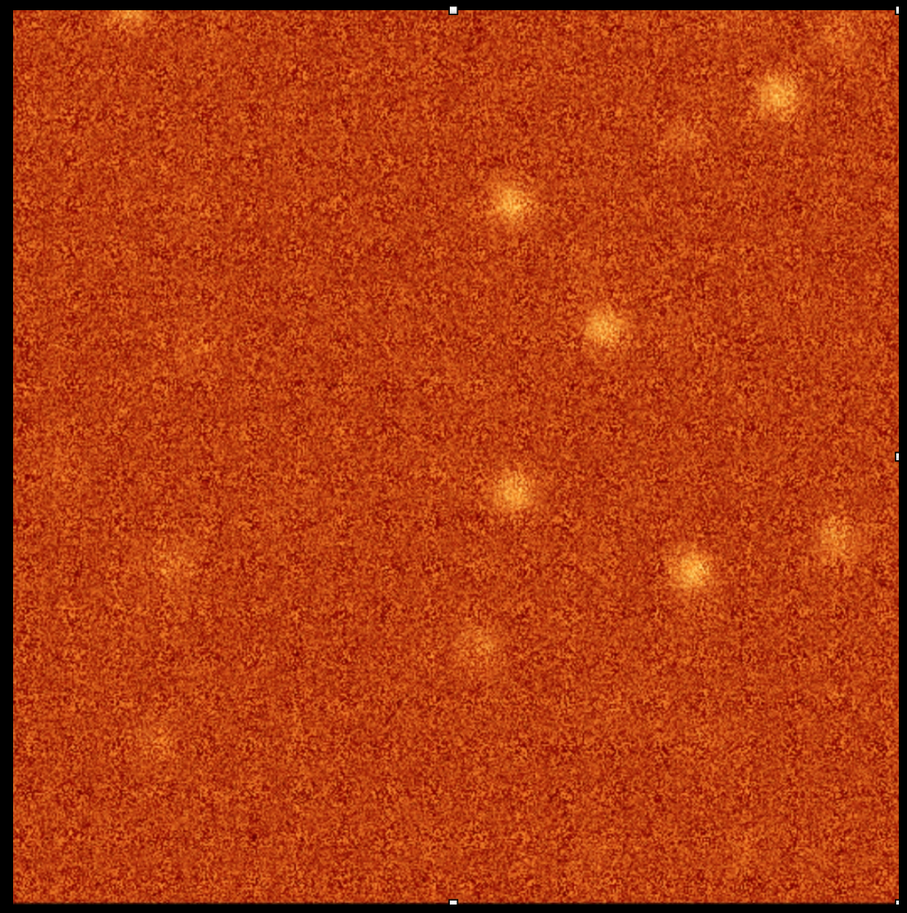
* *intrinsically* brightest emission-line

* Hα not possible... yet

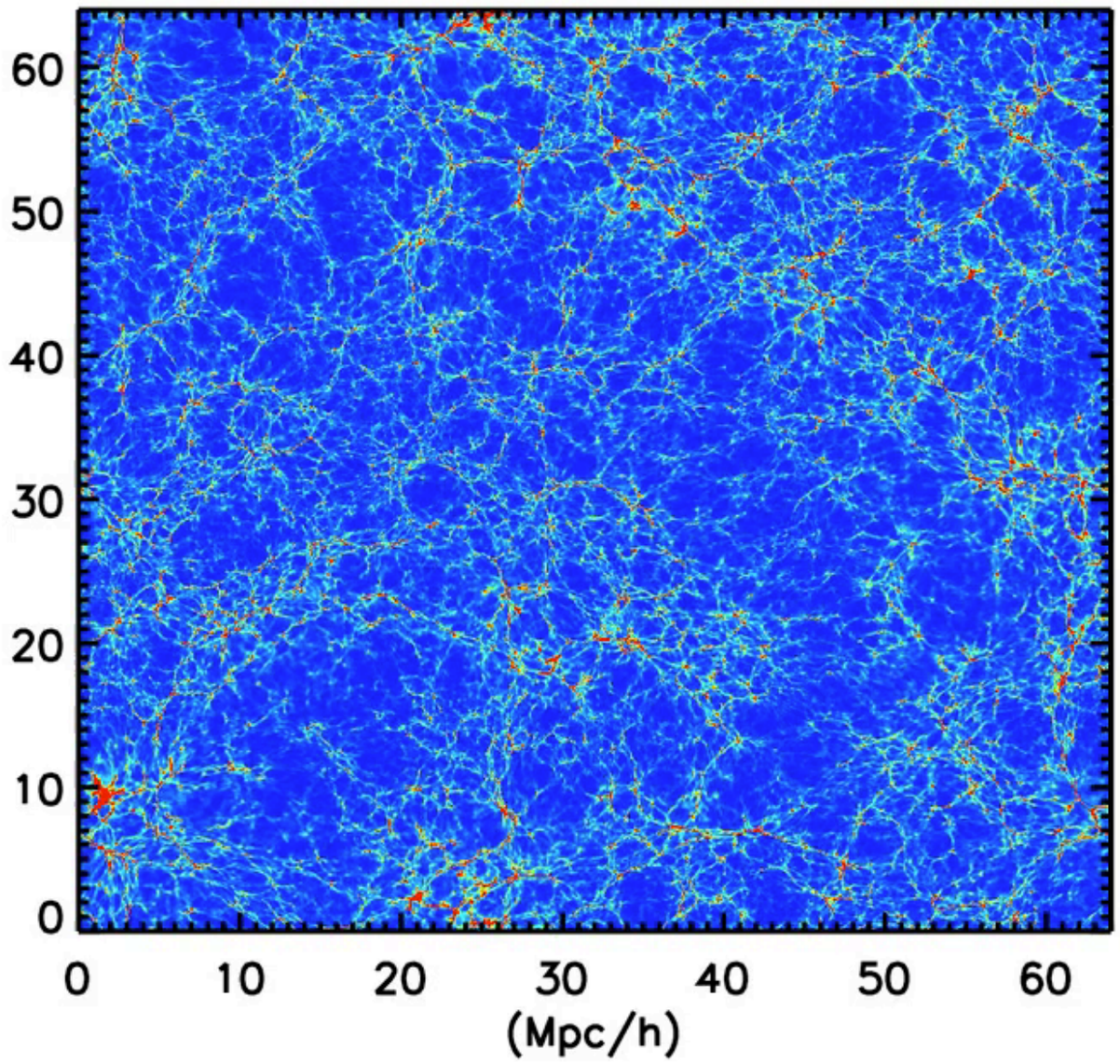
* very sensitive to neutral hydrogen -> study reionization

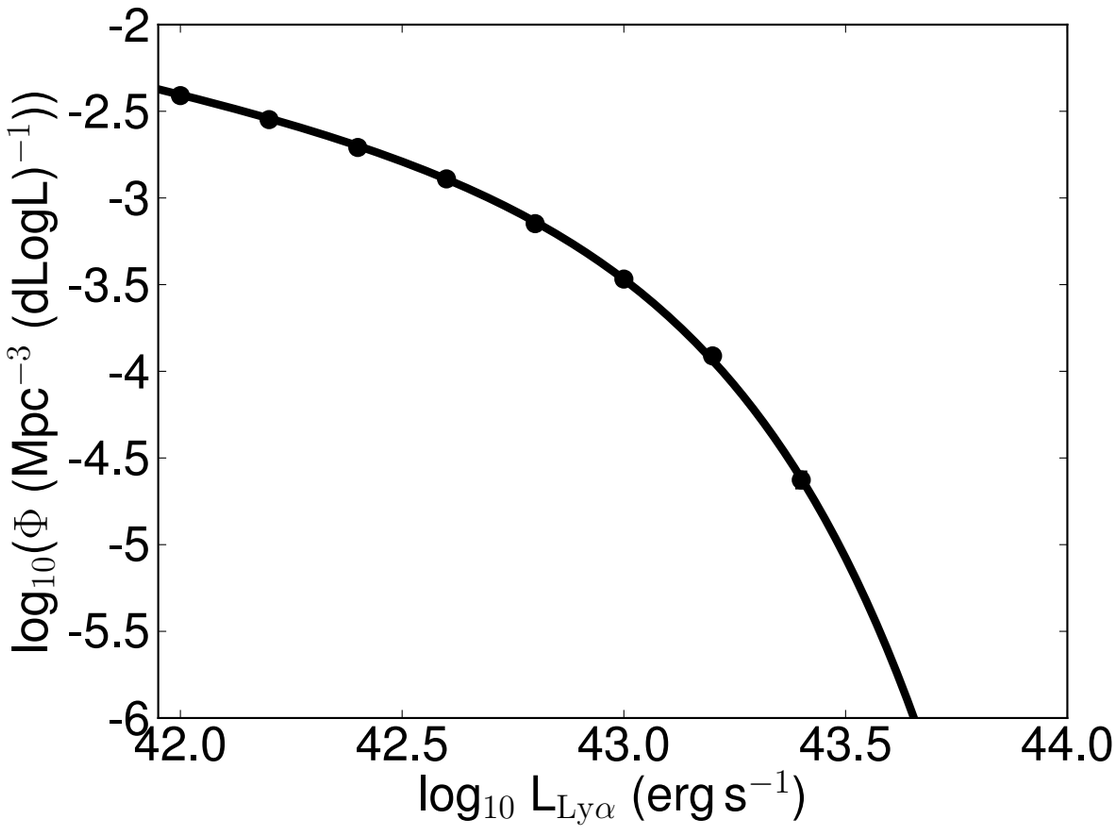






Redshift z~5.5 (Universe 1 billion year old): almost completely ionised

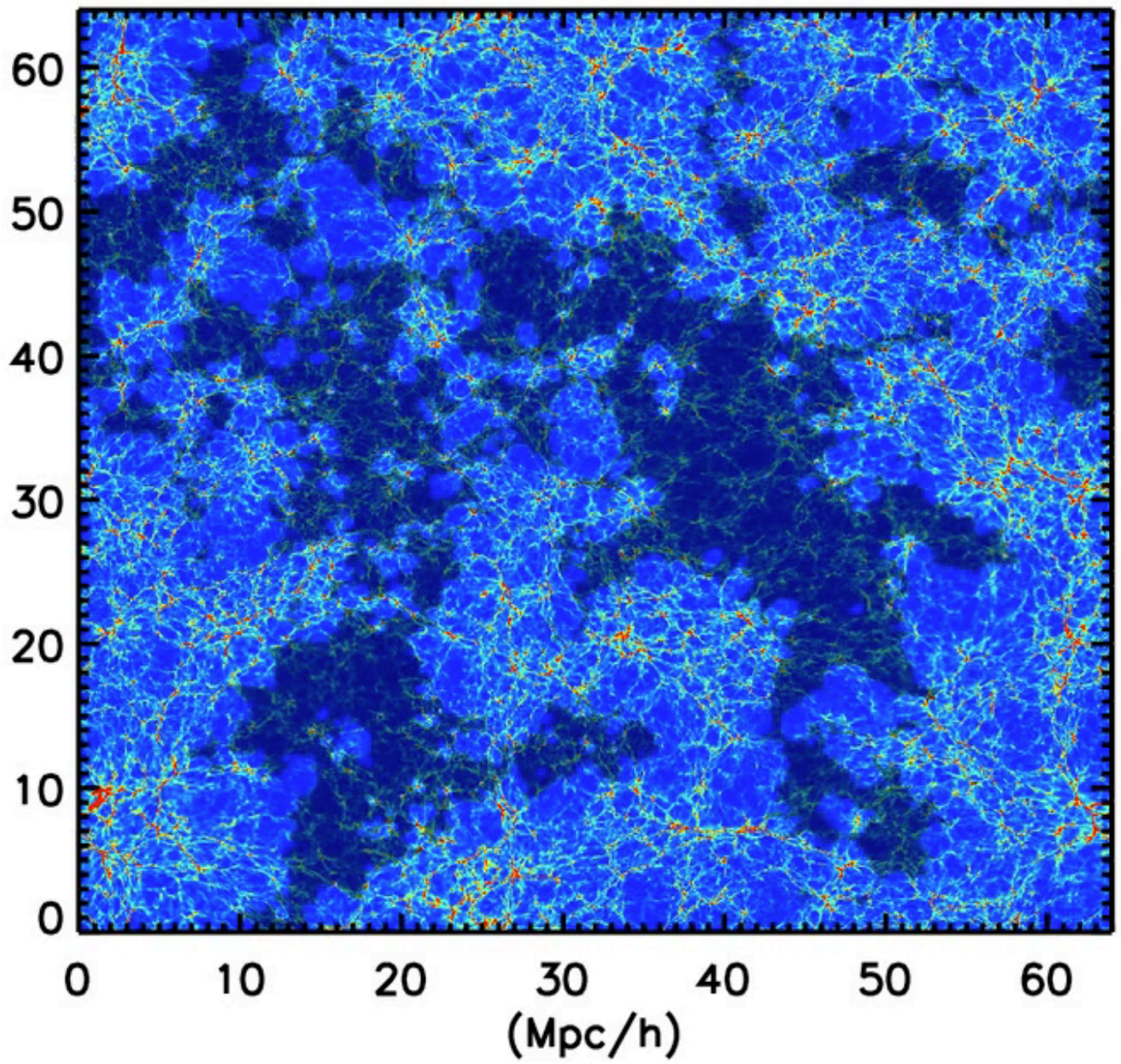




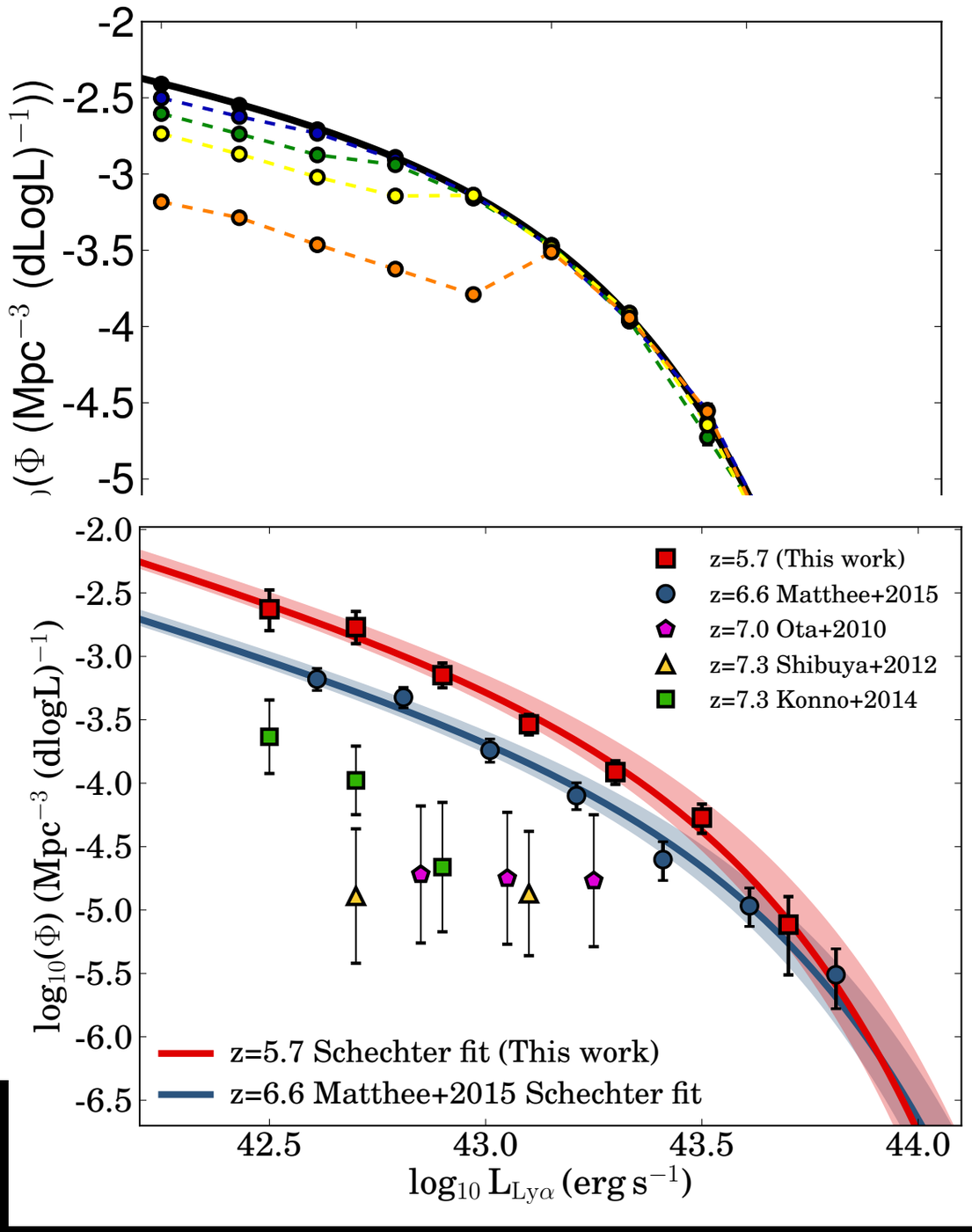
Simulation by Paul Shapiro +

Matthee et al. 2015 MNRAS 451, 4919

Redshift z~6.5 (Universe 0.8 billion year old): neutral bubbles appear



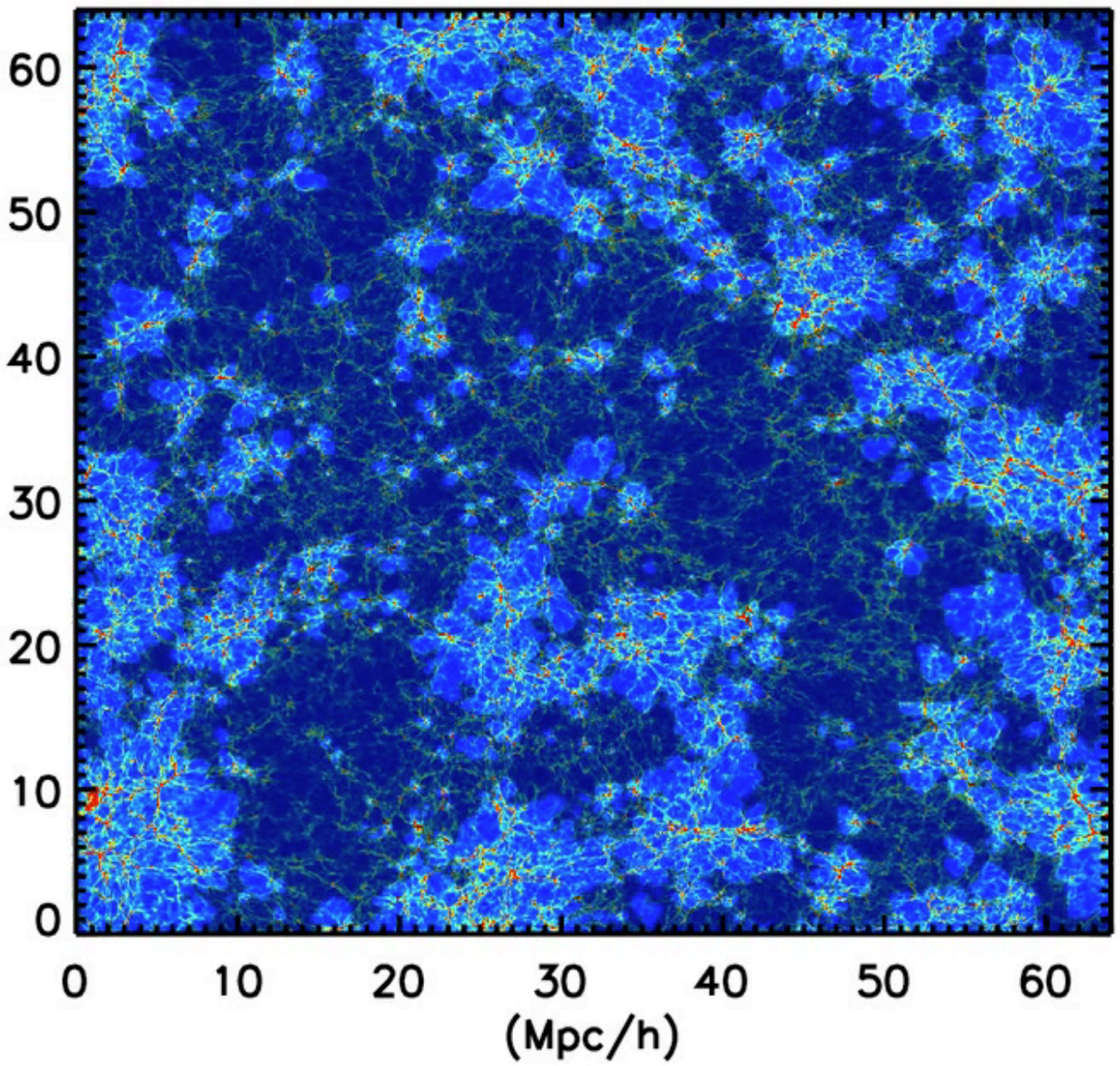
Simulation by Paul Shapiro +



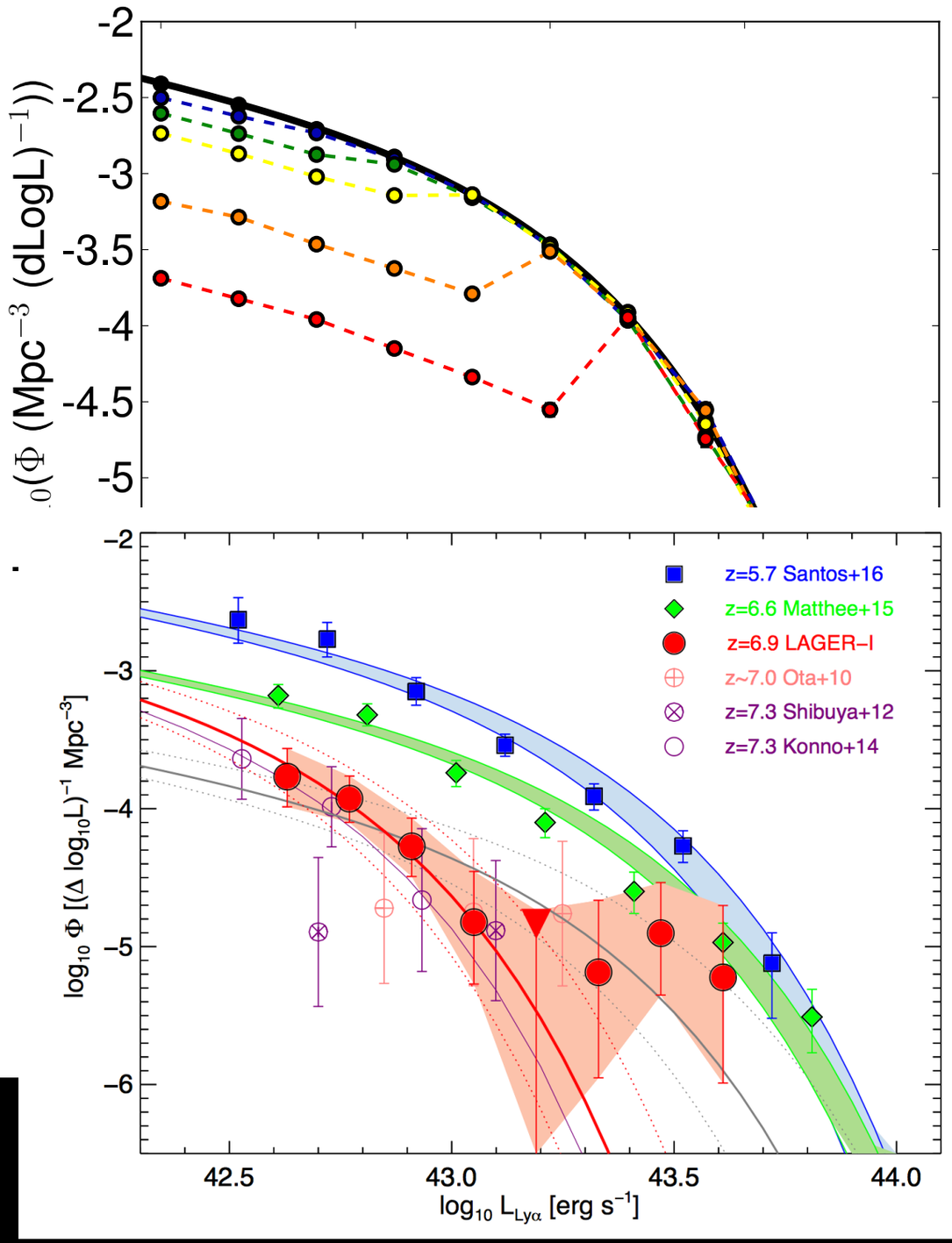
Matthee et al. 2015 MNRAS 451, 4919

Santos, Sobral & Matthee, 2016, MNRAS, 463, 1678

Redshift z~6.9-7.3 (Universe 0.7 billion year old): more neutral bubbles appear



Simulation by Paul Shapiro +

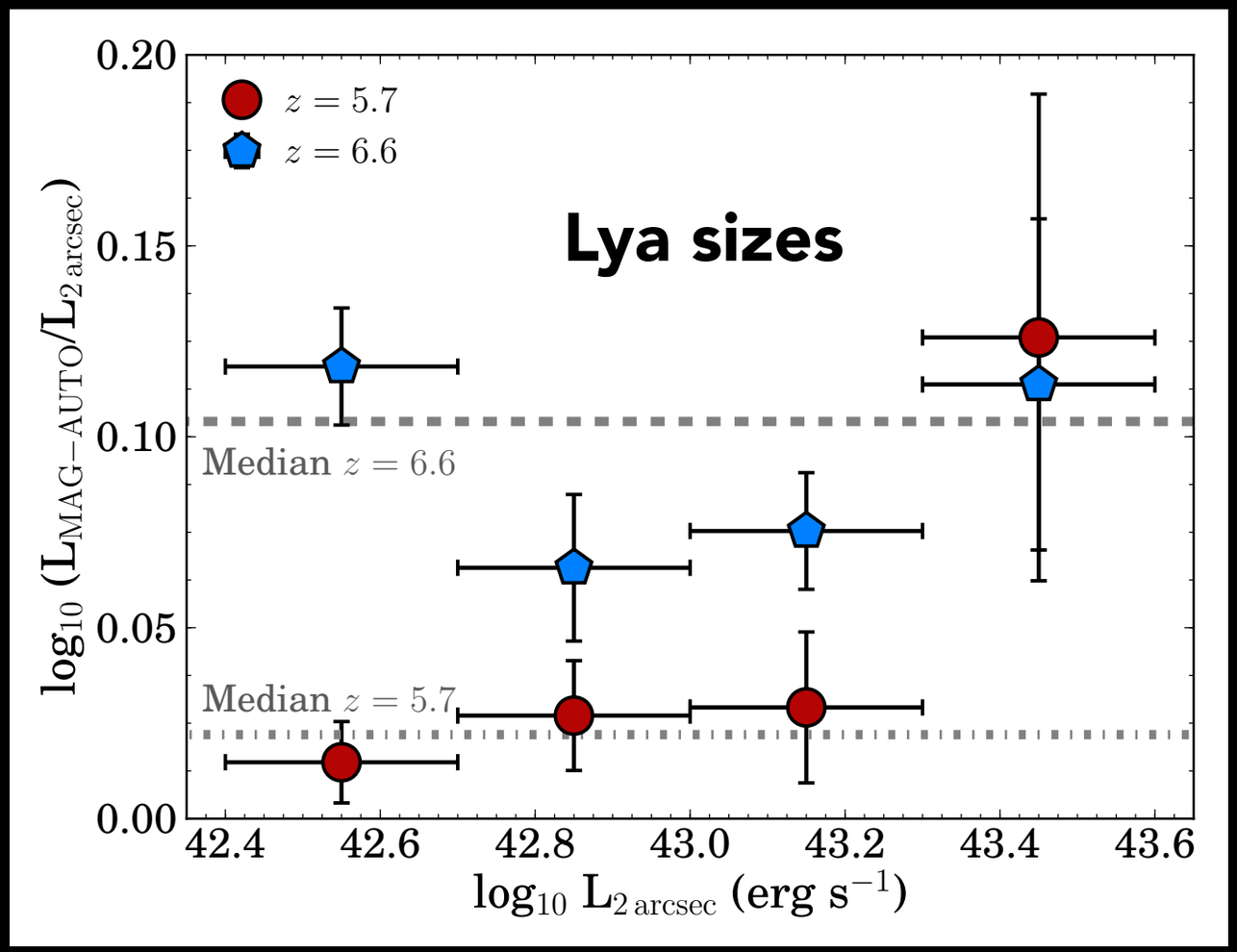


Zheng+17; Ota+10, Shibuya+12,Konno+14

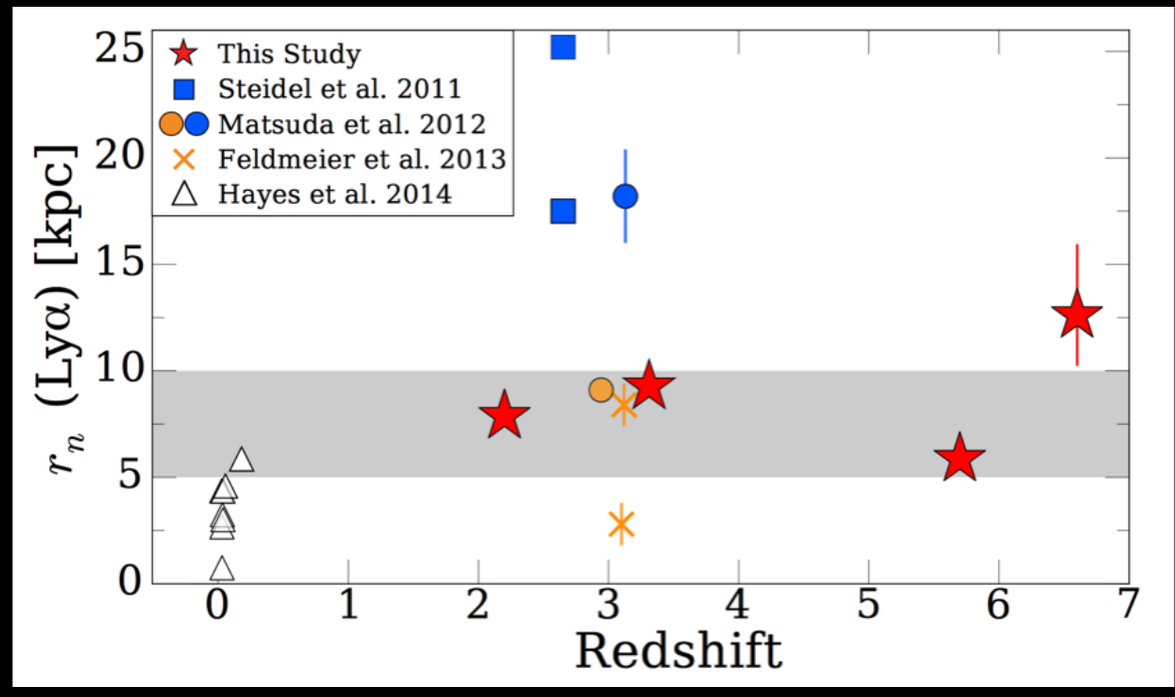
Lya & reionization, v2

Faint LAEs:

* more extended at z=6.6 than at z=5.7!



Santos, Sobral & Matthee, 2016, MNRAS, 463, 1678

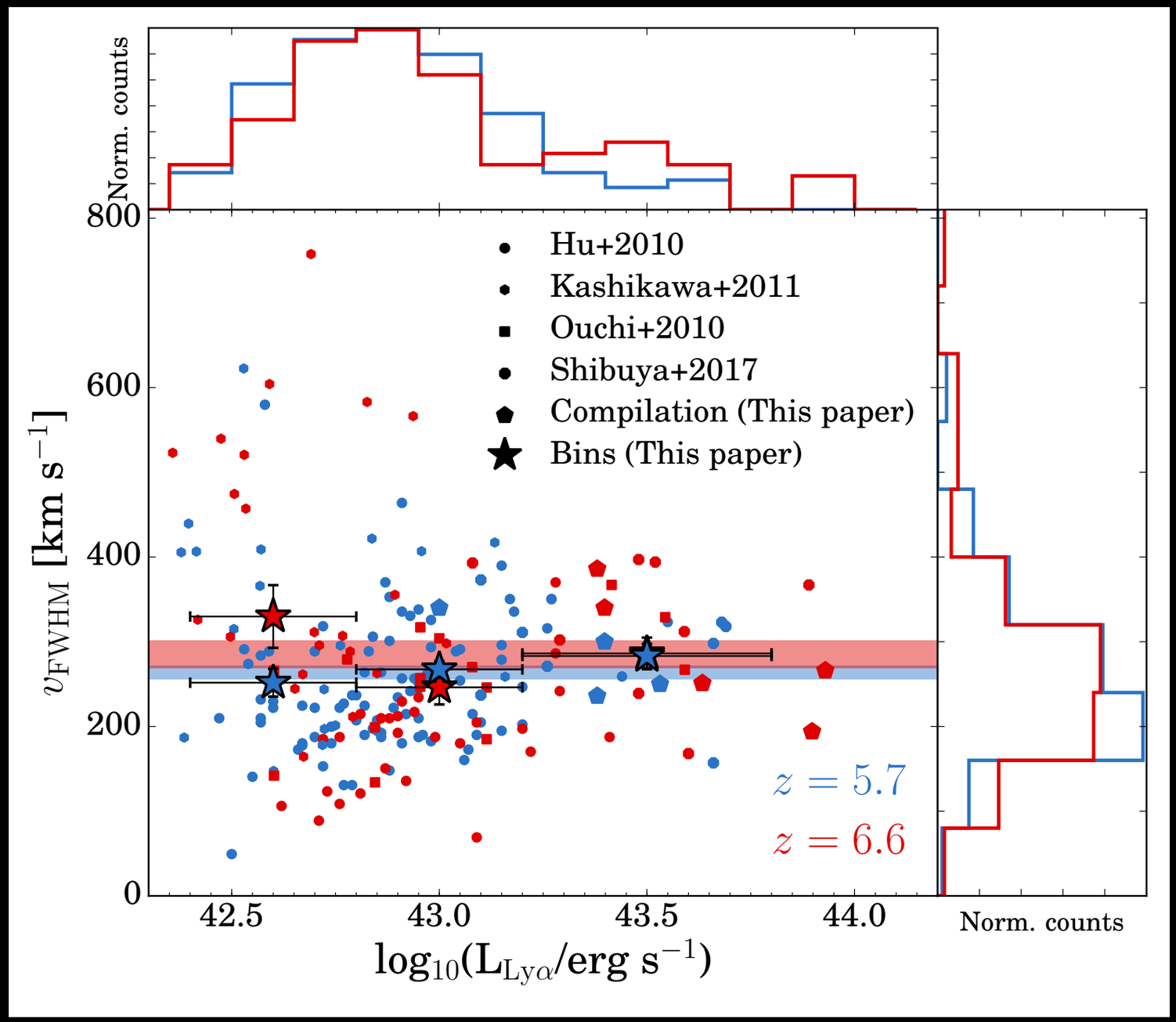


Momose+2014, MNRAS,442,110

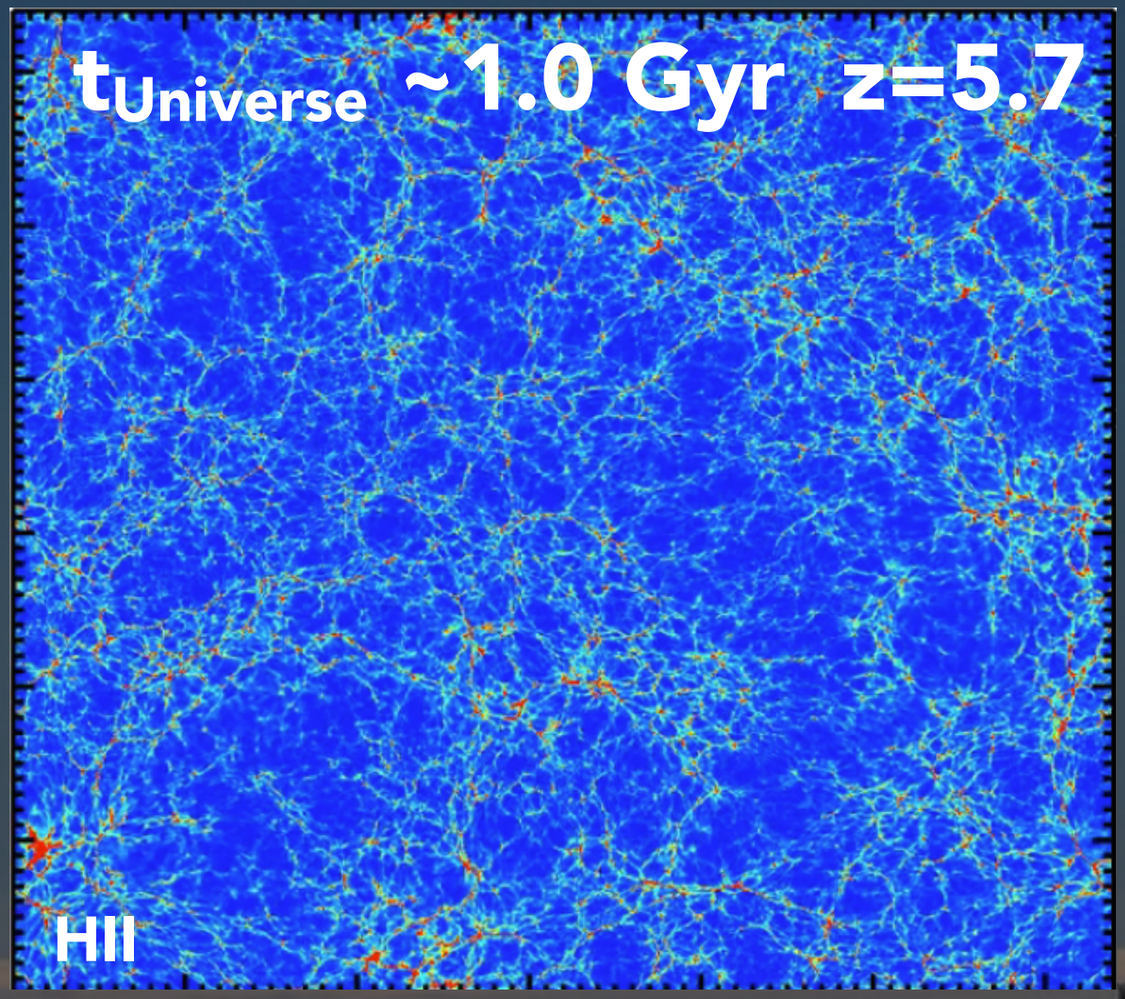
Lyα & reionization, v2

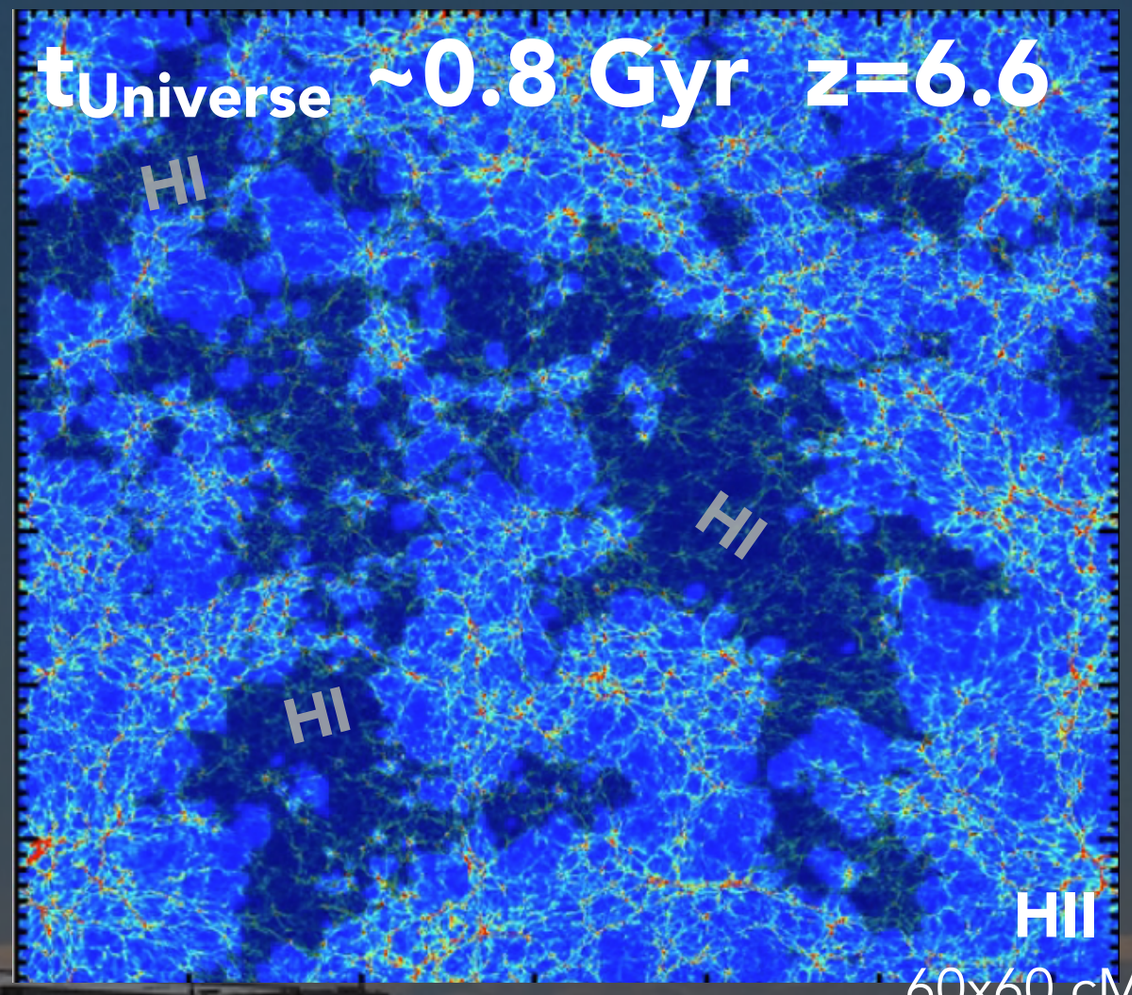
Faint LAEs:

* tentatively broader at z=6.6!

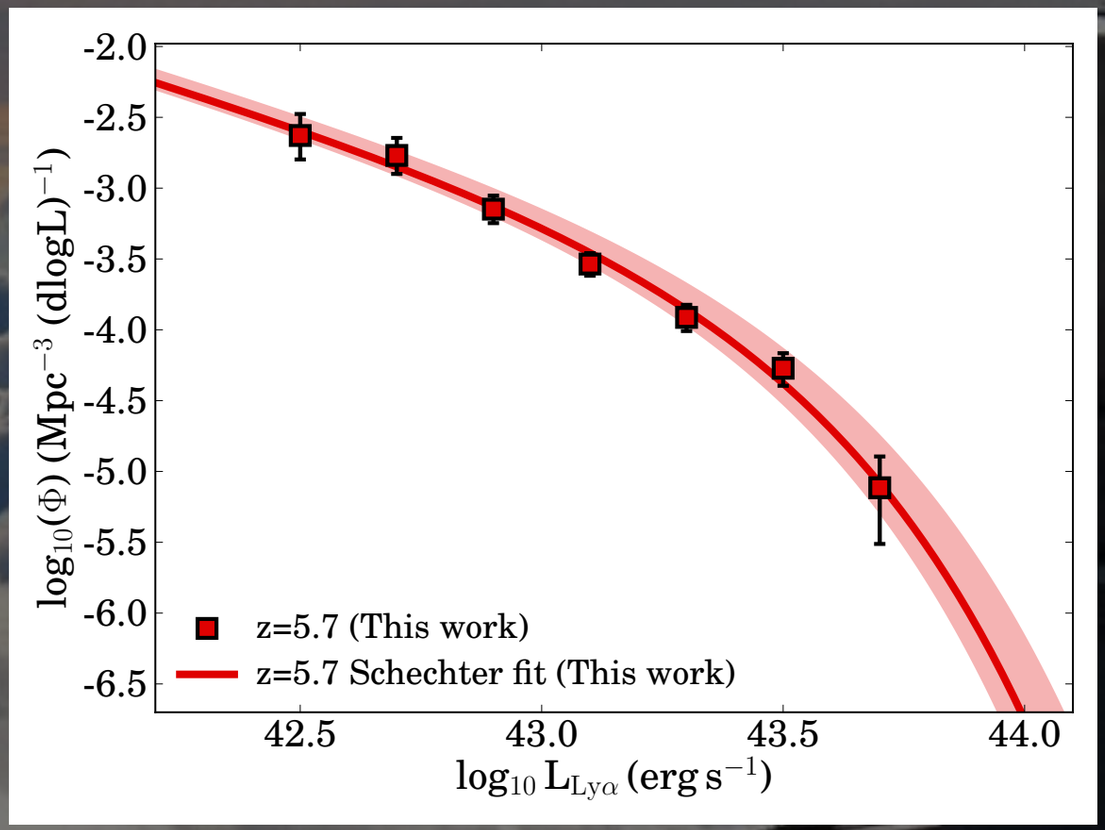


Matthee+2017, MNRAS, 472, 772

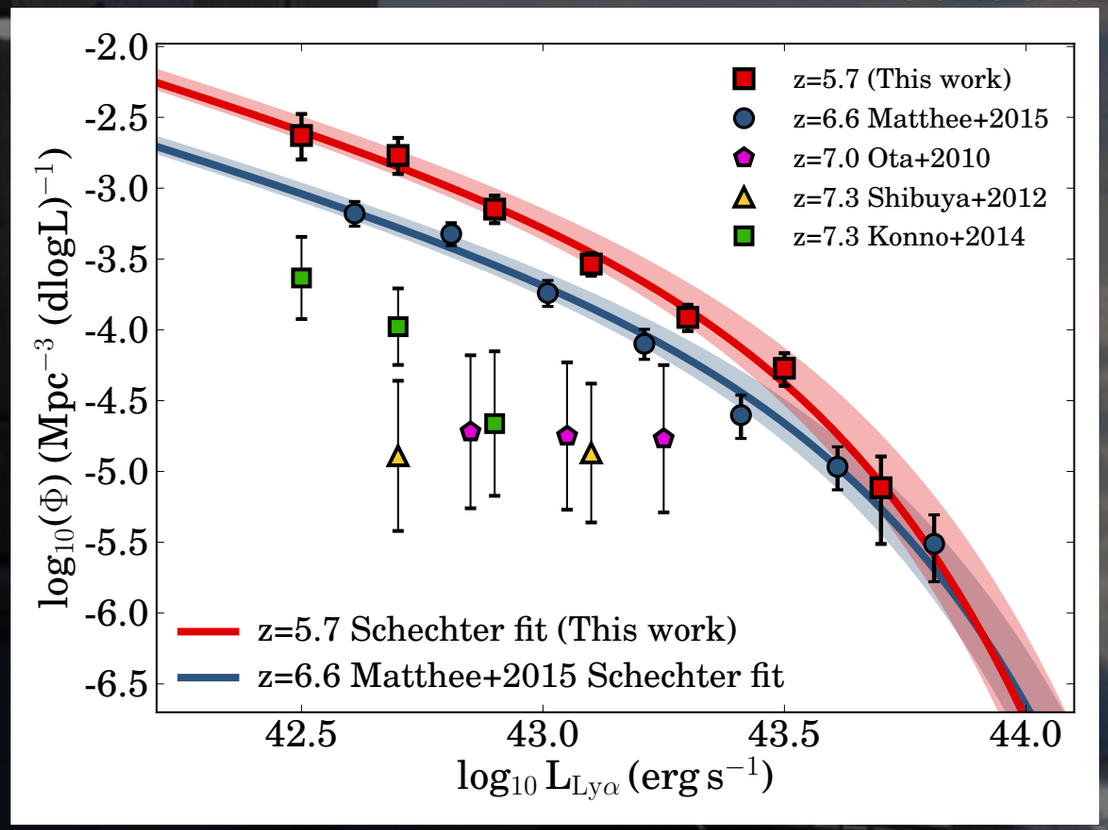




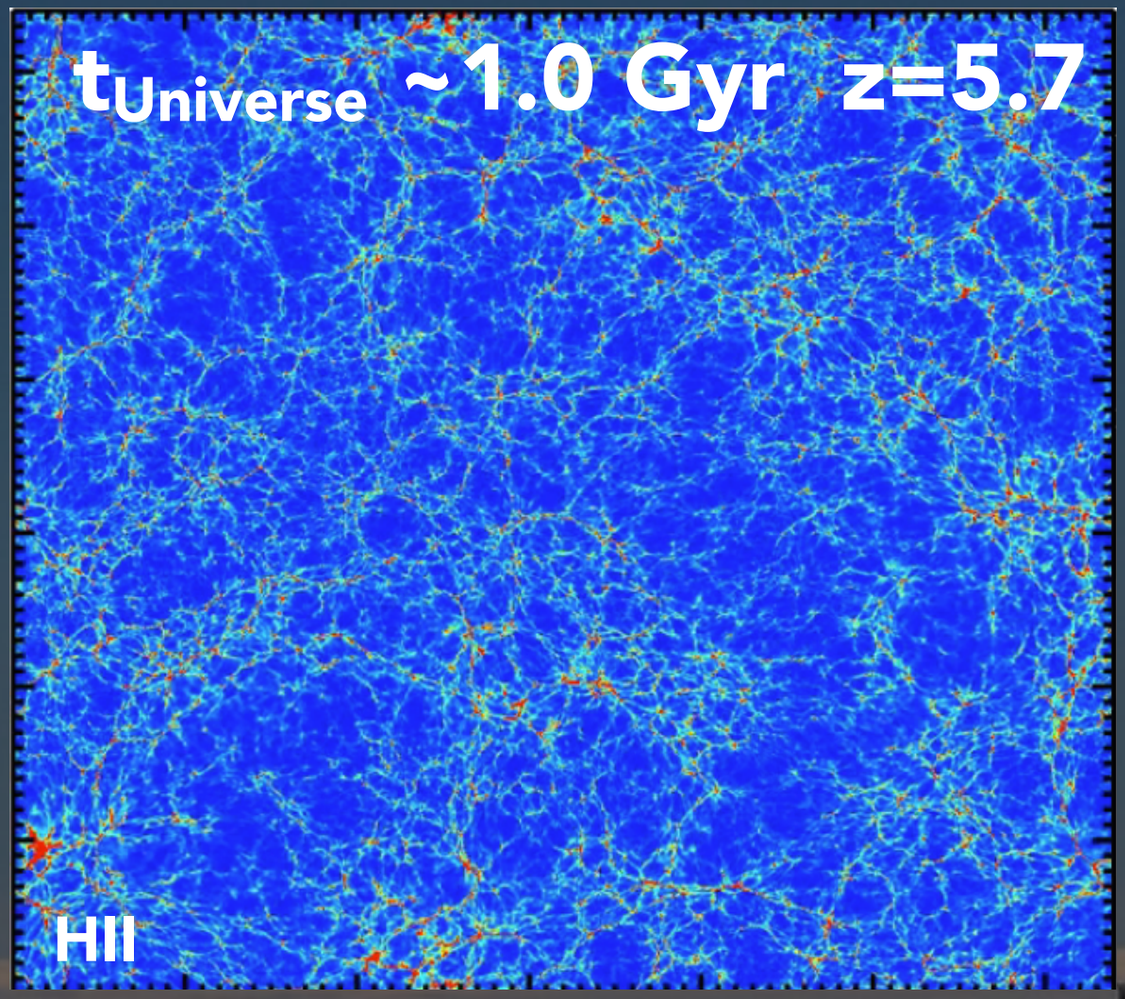
60x60 cMpc

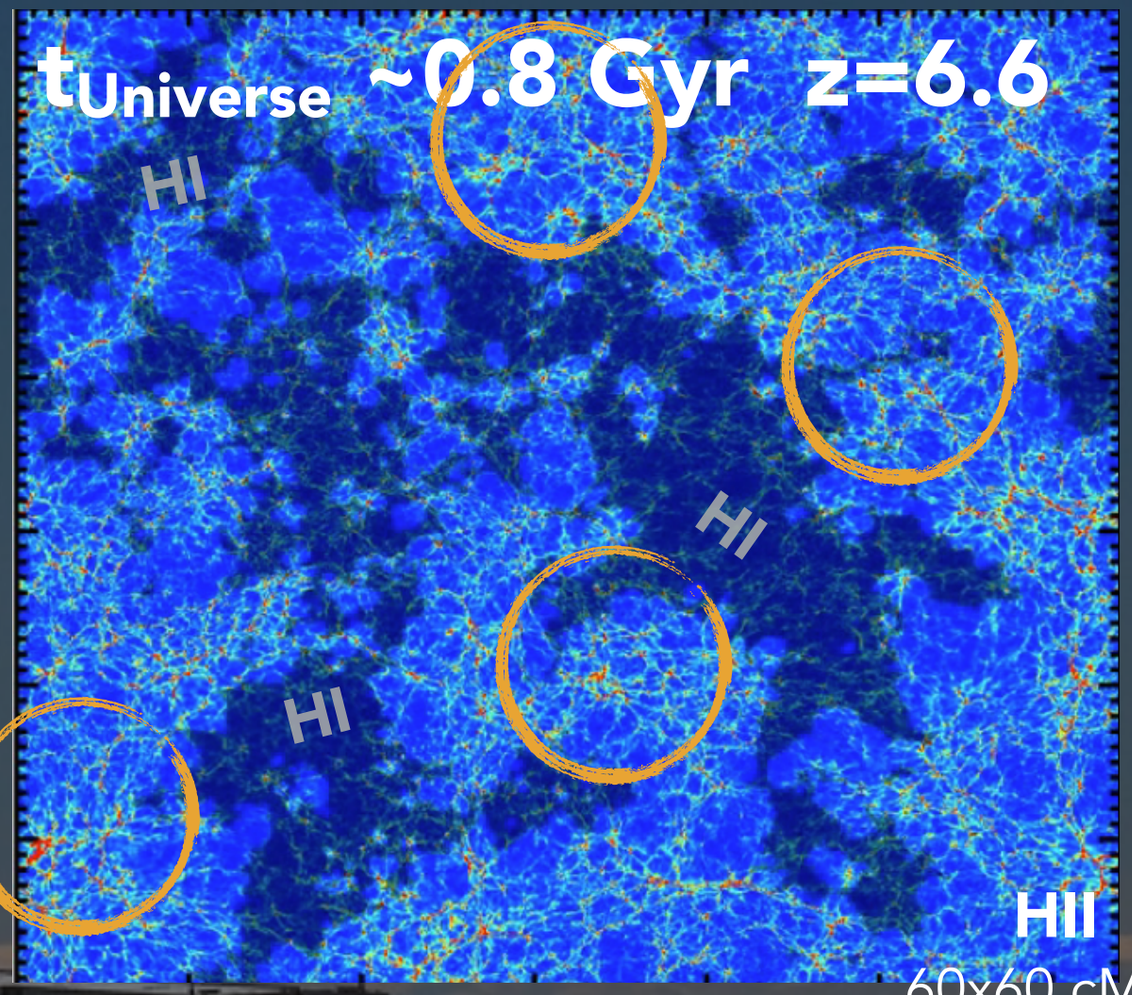


Matthee et al. 2015 MNRAS 451, 4919

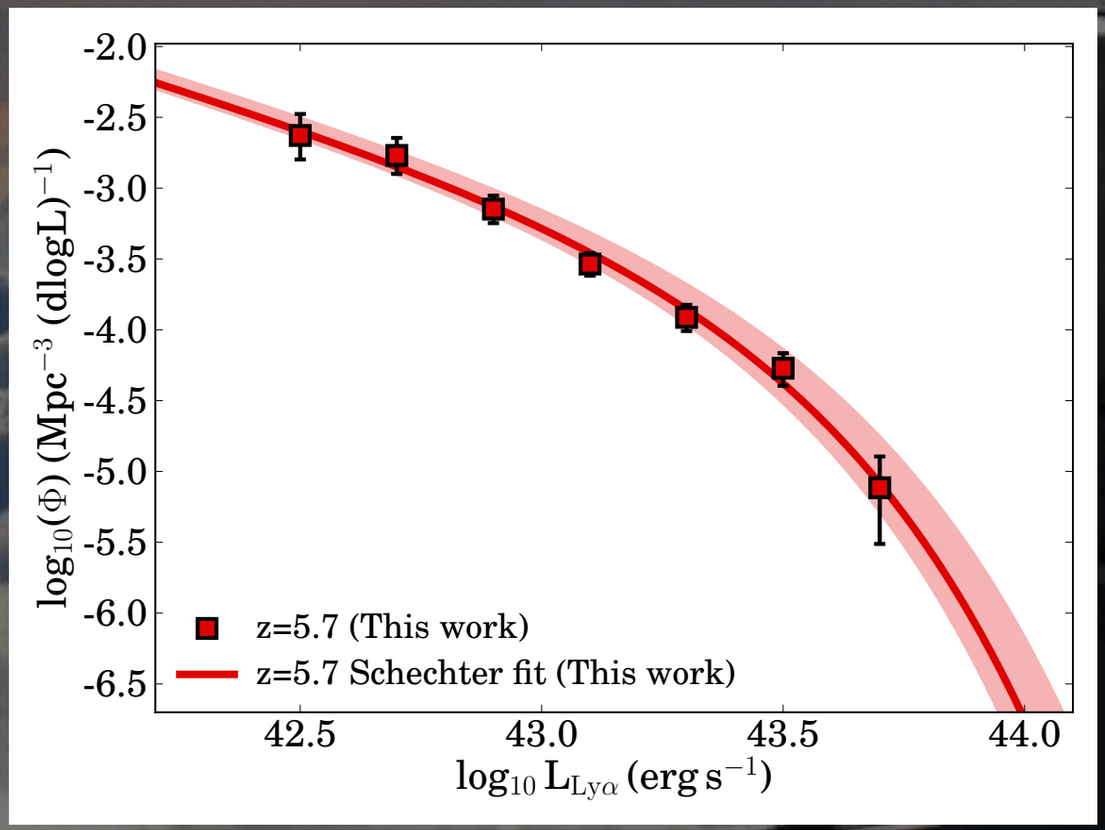


Santos, Sobral & Matthee, 2016, MNRAS, 463, 1678

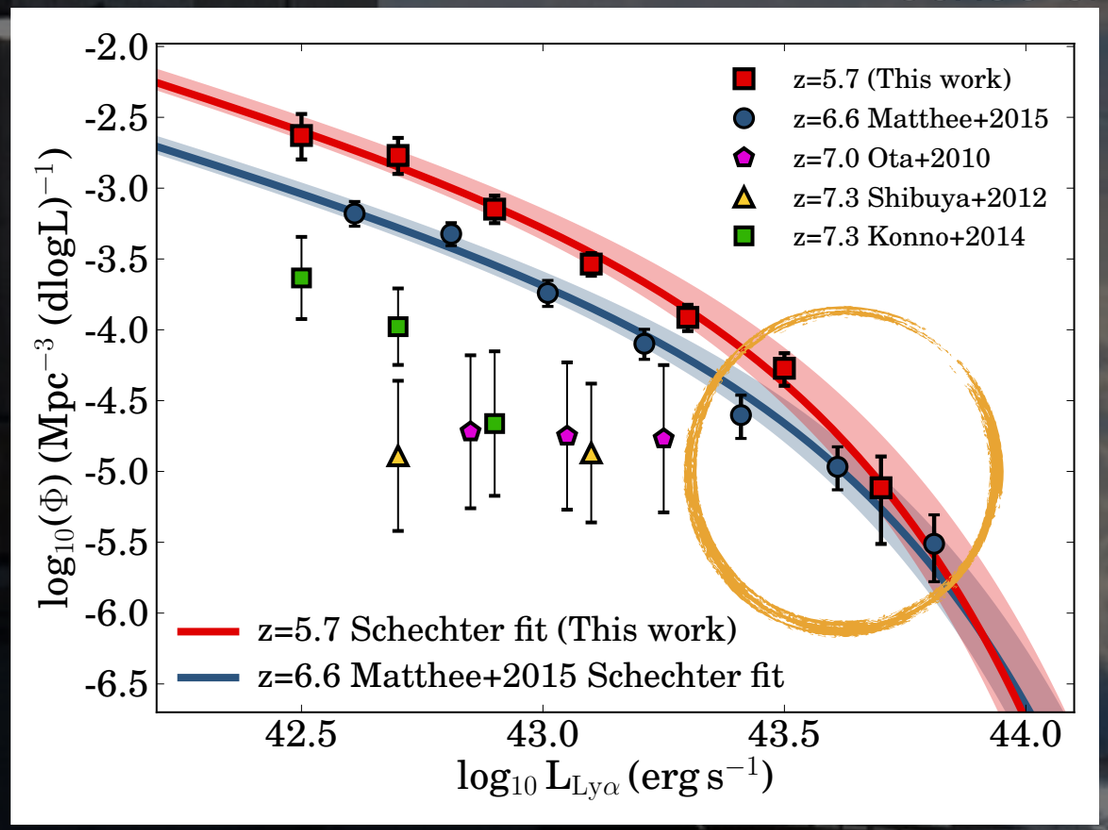




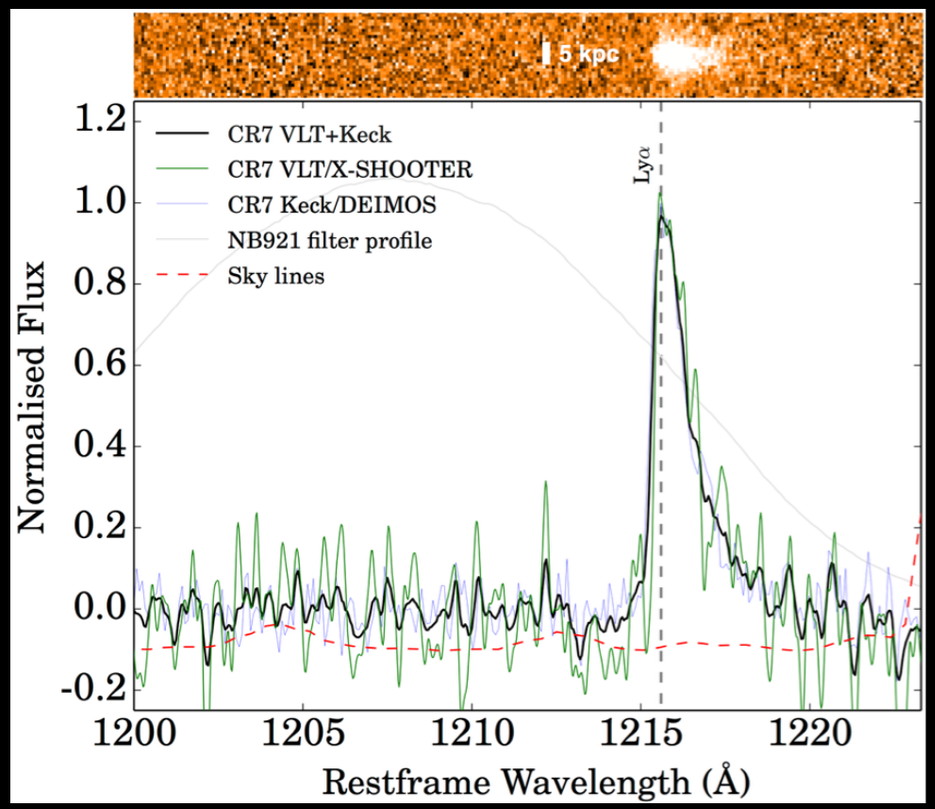
60x60 cMpc

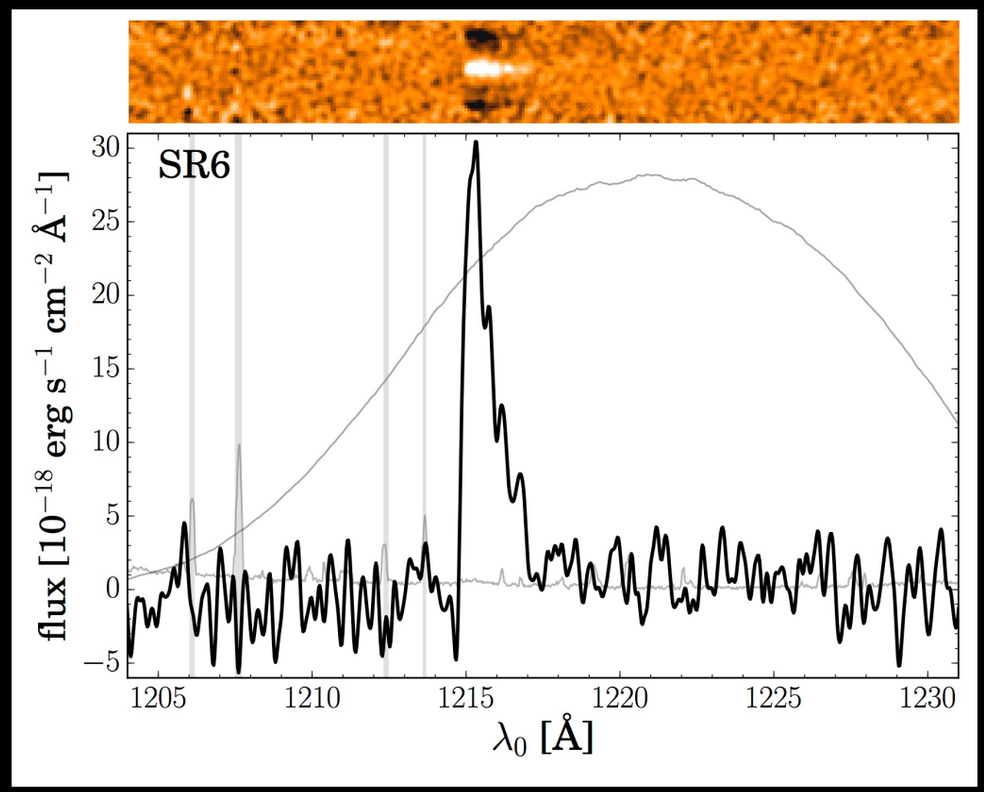


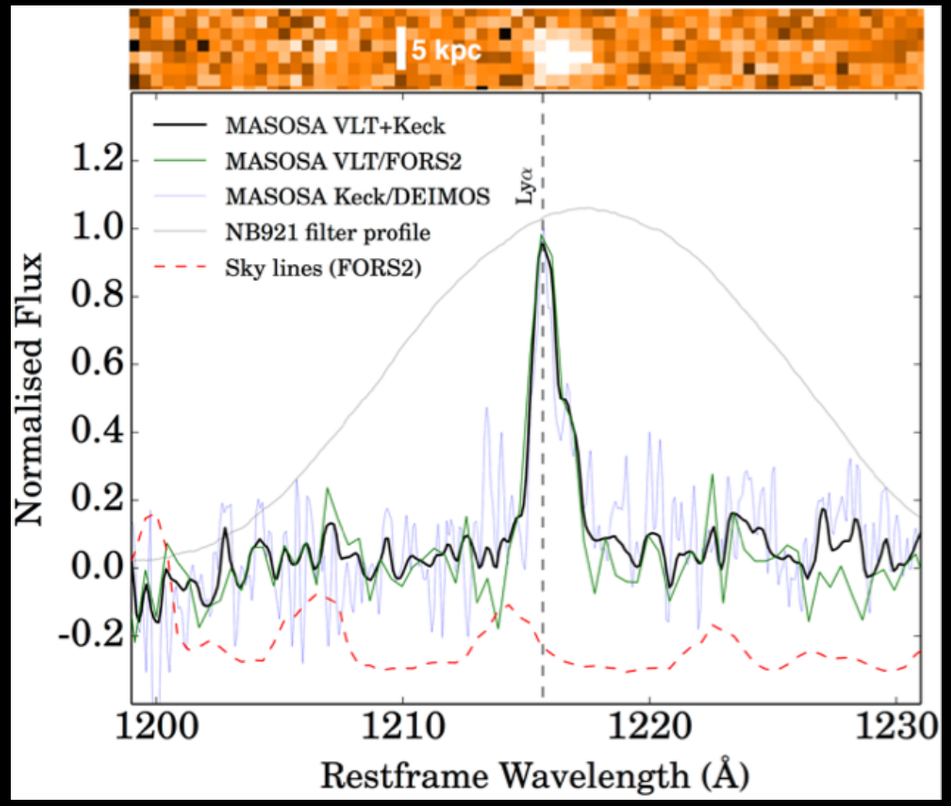
Matthee et al. 2015 MNRAS 451, 4919

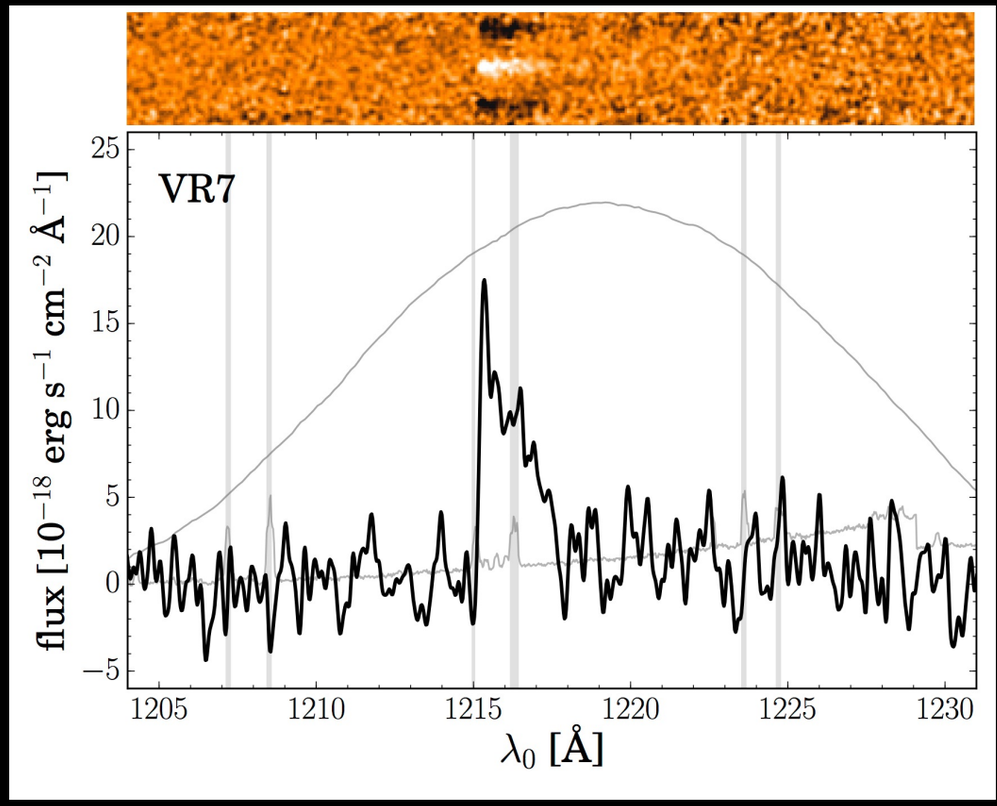


Santos, Sobral & Matthee, 2016, MNRAS, 463, 1678



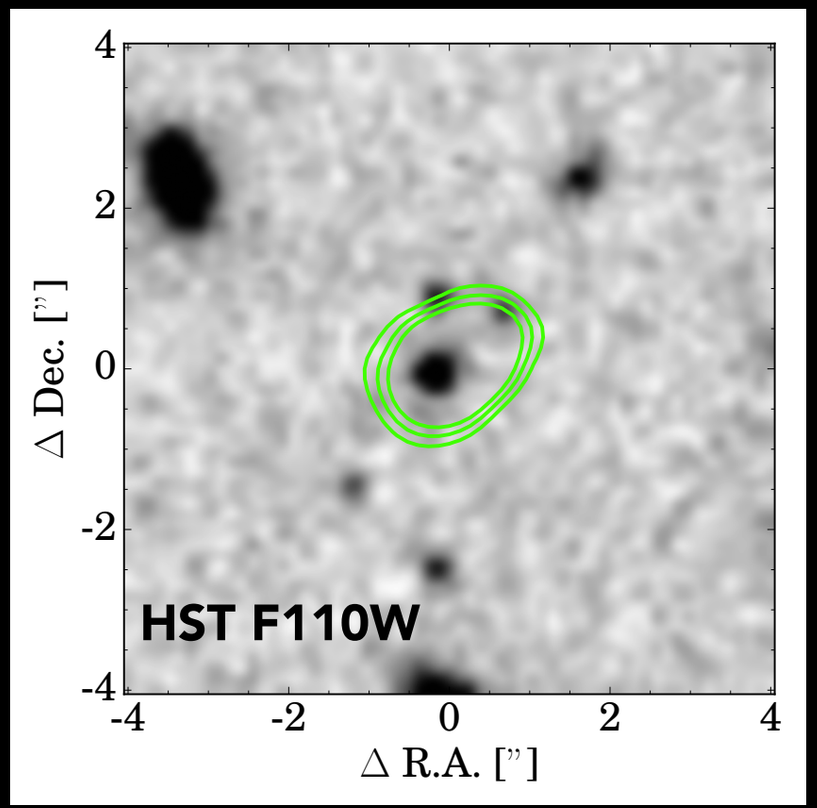


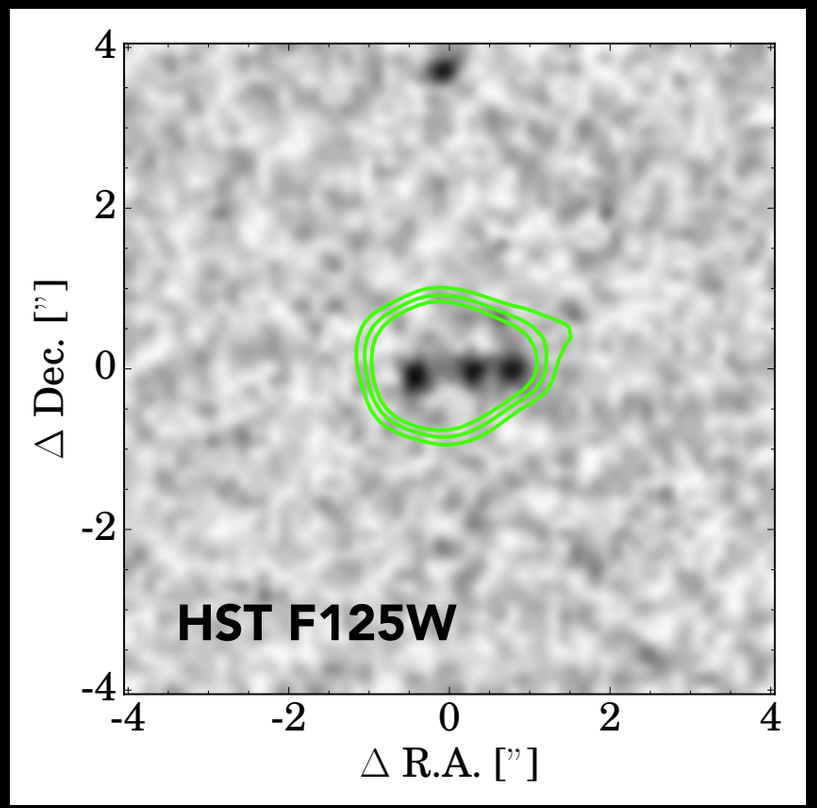


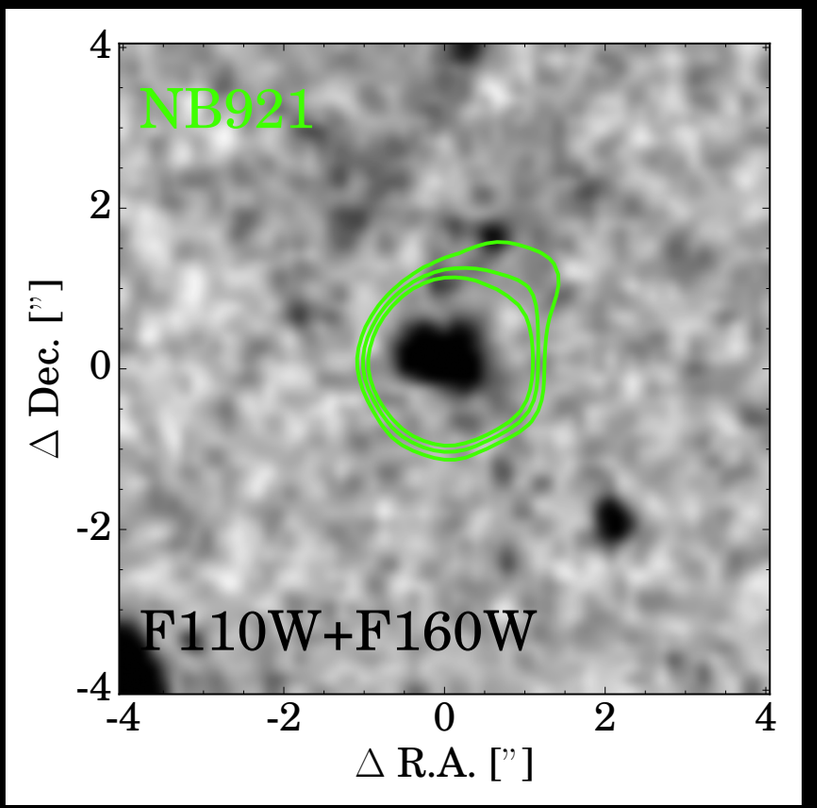


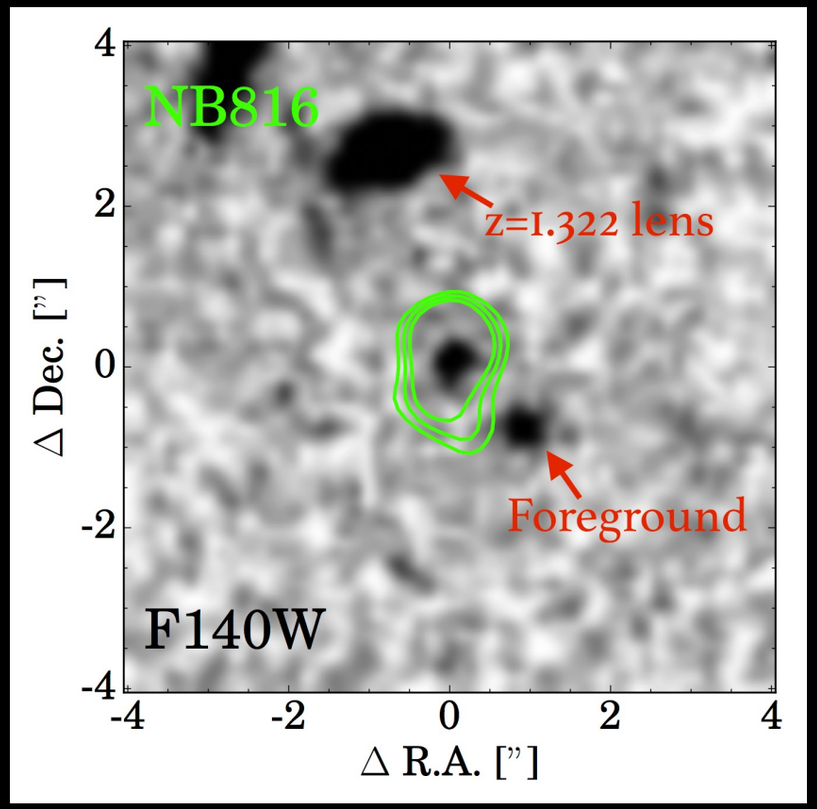
~1-2hr exposure time on 8m telescopes

Many luminous z~6-7 LAEs have multiple-components







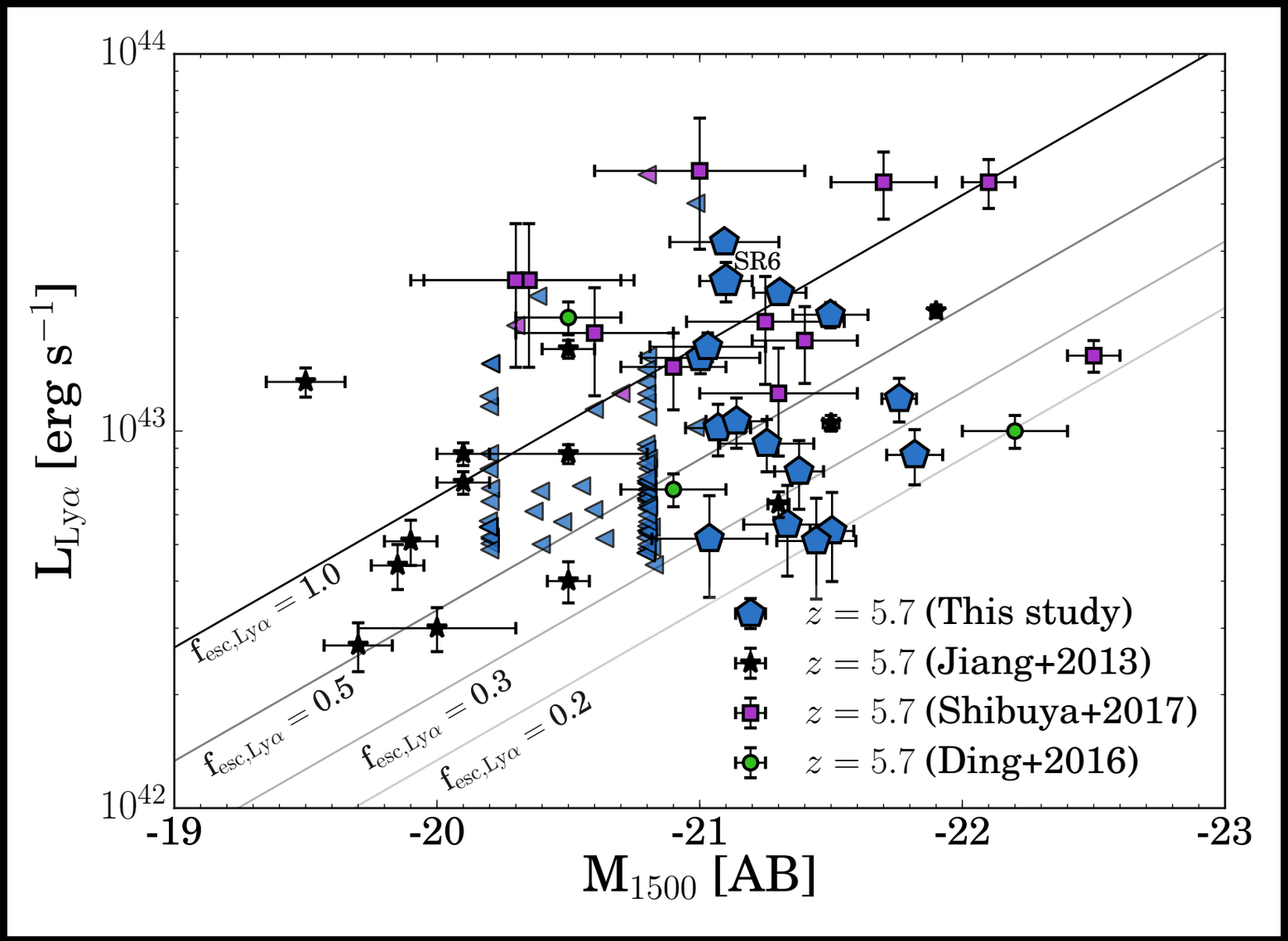


images are 20x20 kpc

Ouchi et al. 2013
Jiang et al. 2013
Sobral et al. 2015
Matthee et al. 2017c

LBGs see Bowler et al. 2017

Among LAEs at z=5.7, no clear relation UV-Lyα luminosity

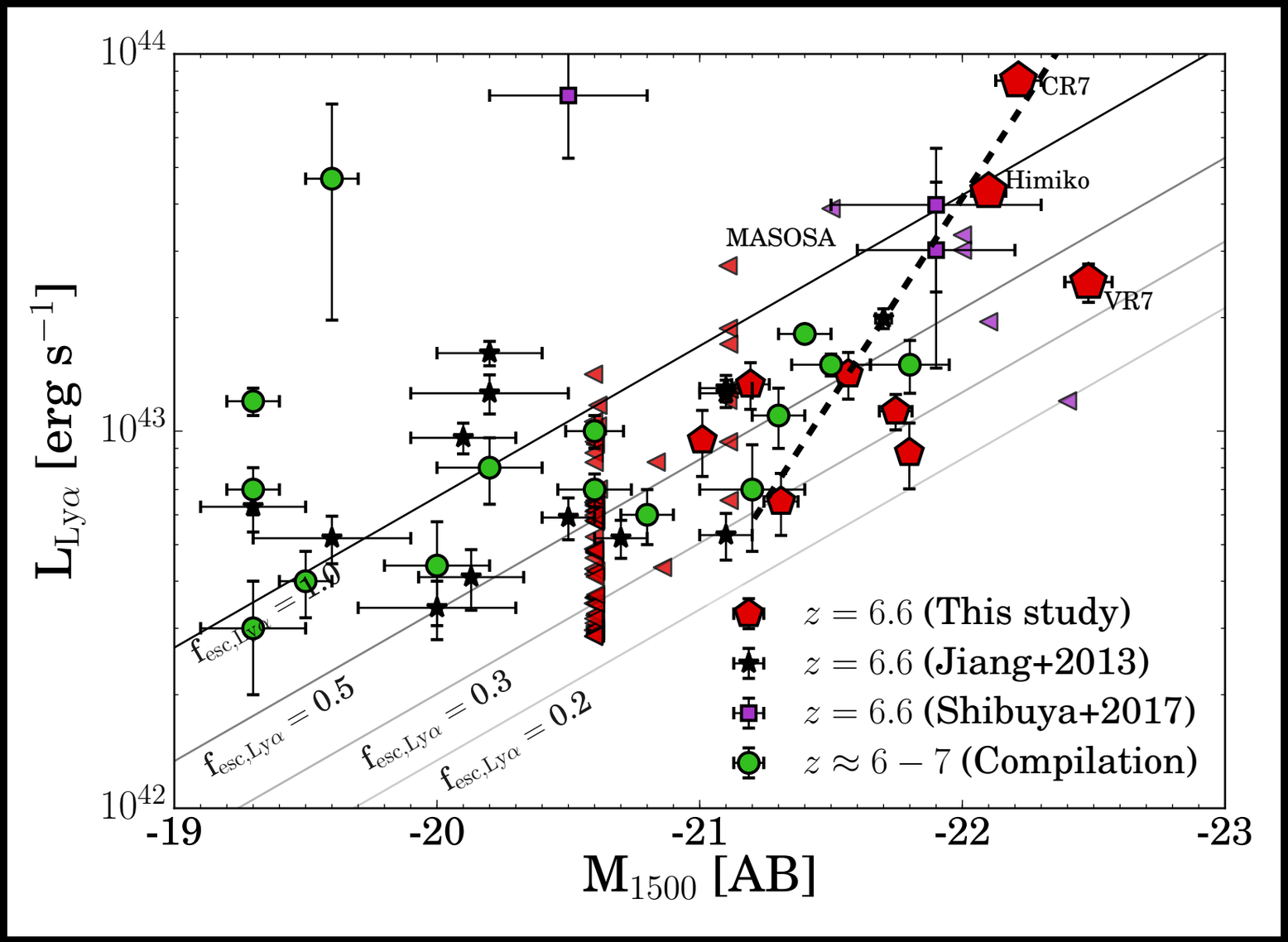


Shallow/wide Lyα survey can pick up UV faint galaxies

see also Ando+2006

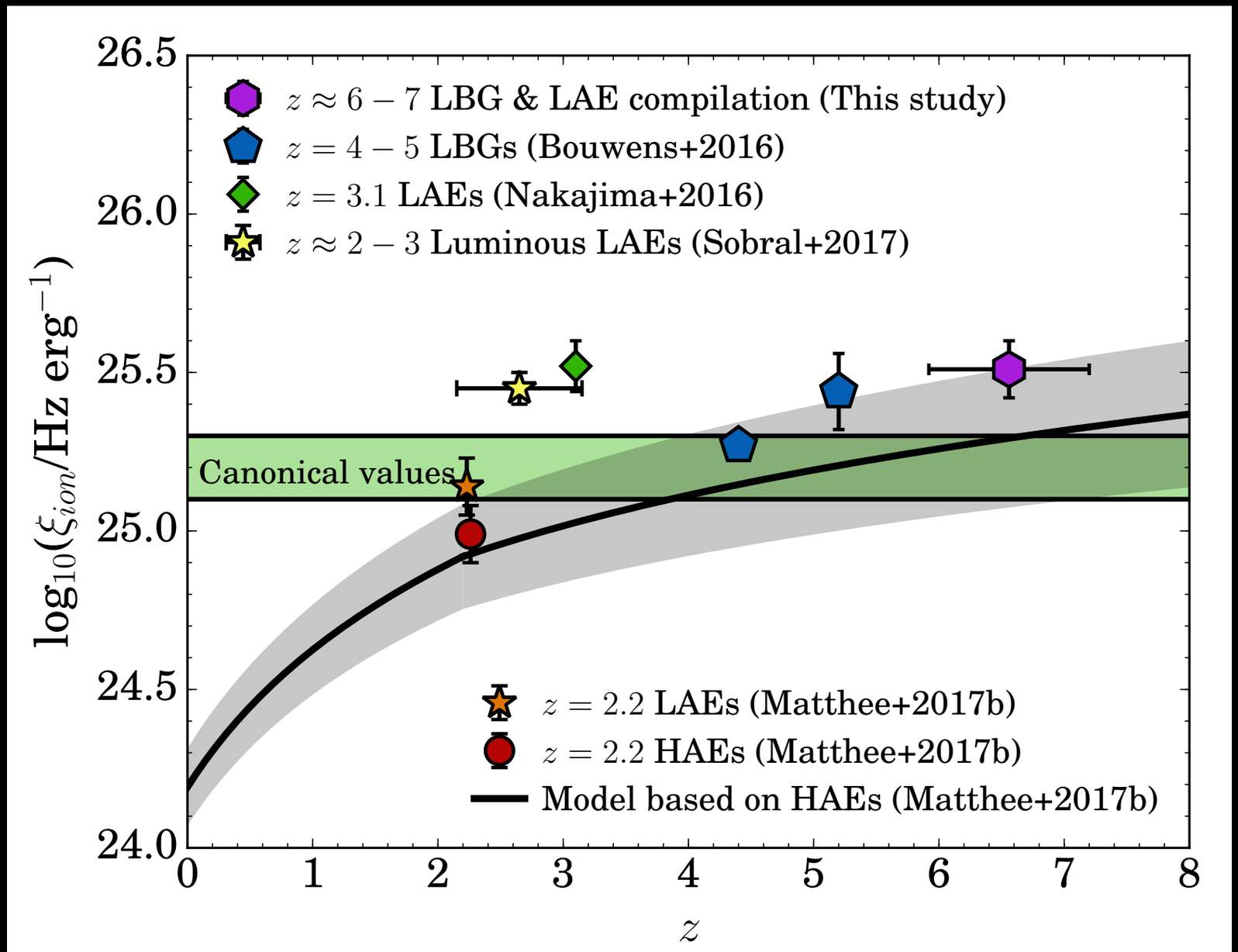
Matthee+2017c, MNRAS, 472, 772

Among LAEs at z=6.6, potential relation UV-Lyα luminosity



Induced by increased HI in reionization era?

Matthee+2017c, MNRAS, 472, 772



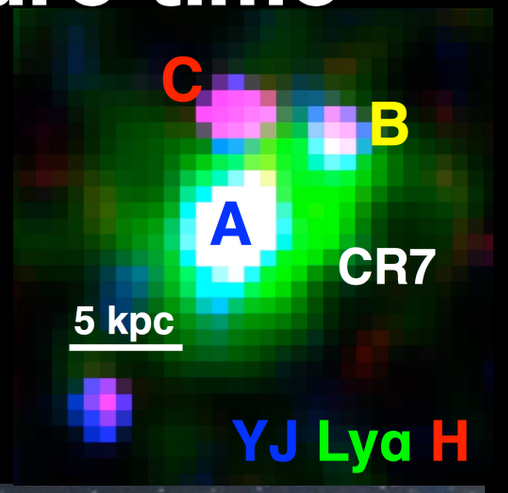
- Typical ξ_{ion} of high-z galaxies is high
- model ξ_{ion} evolution based on Hα EW

model: Matthee et al. 2017b, MNRAS, 465, 3637

ALMA Band 6 Cycle 3 — 6 hours exposure time

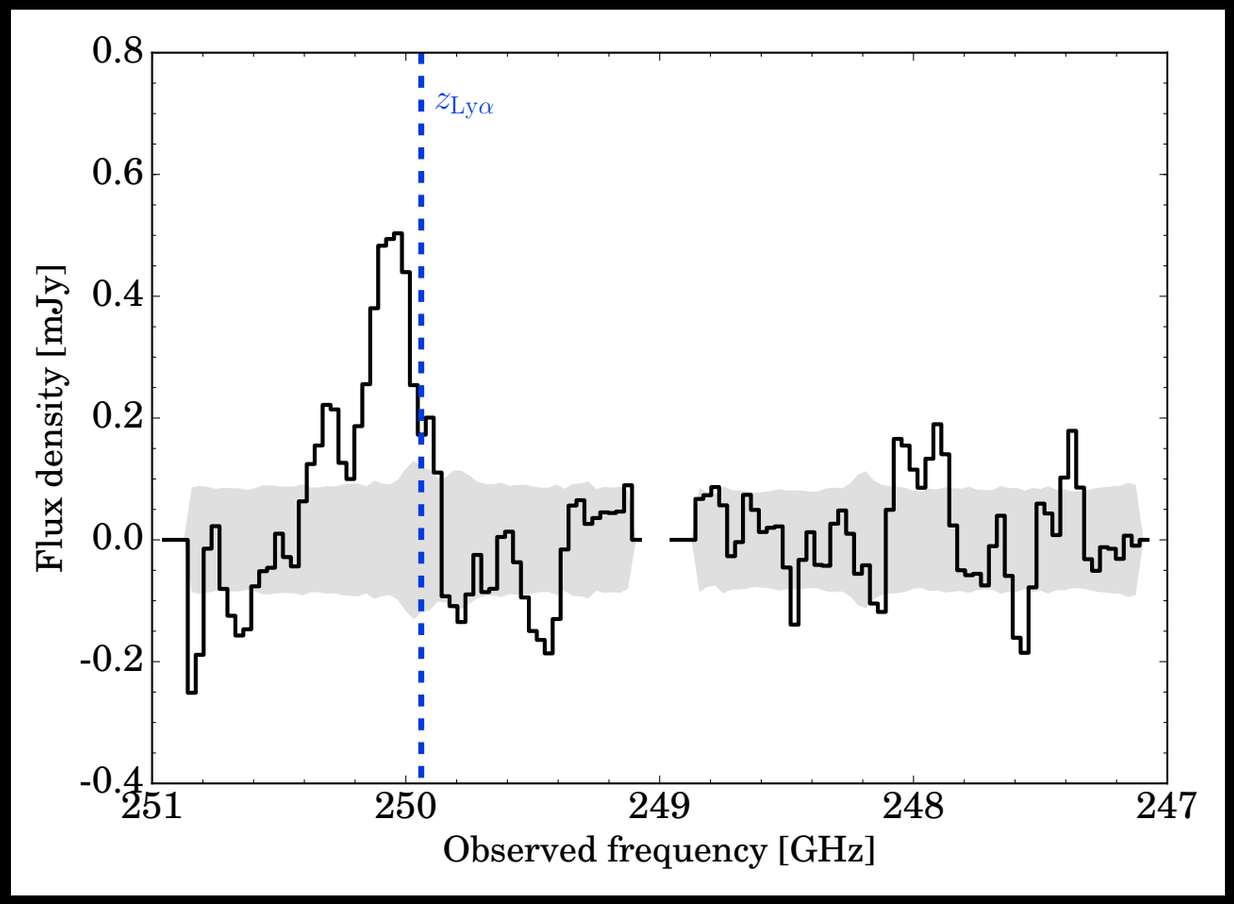
CR7: brightest Lya emitter known

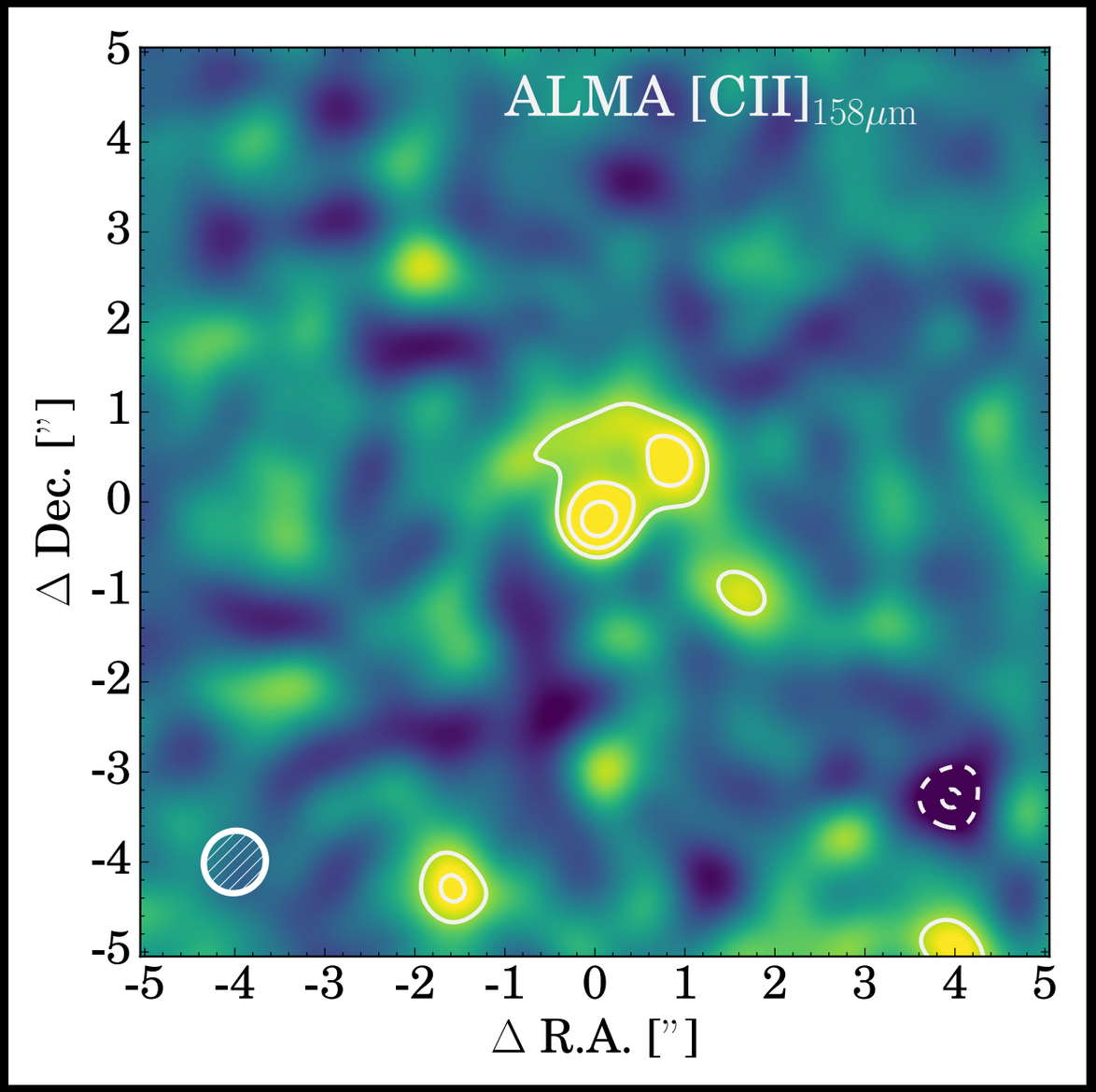
* FIR continuum (dust emission)
* [CII] 158um (fine-structure cooling line)



Matthee et al. arXiv:1709.06569

[CII] EMISSION



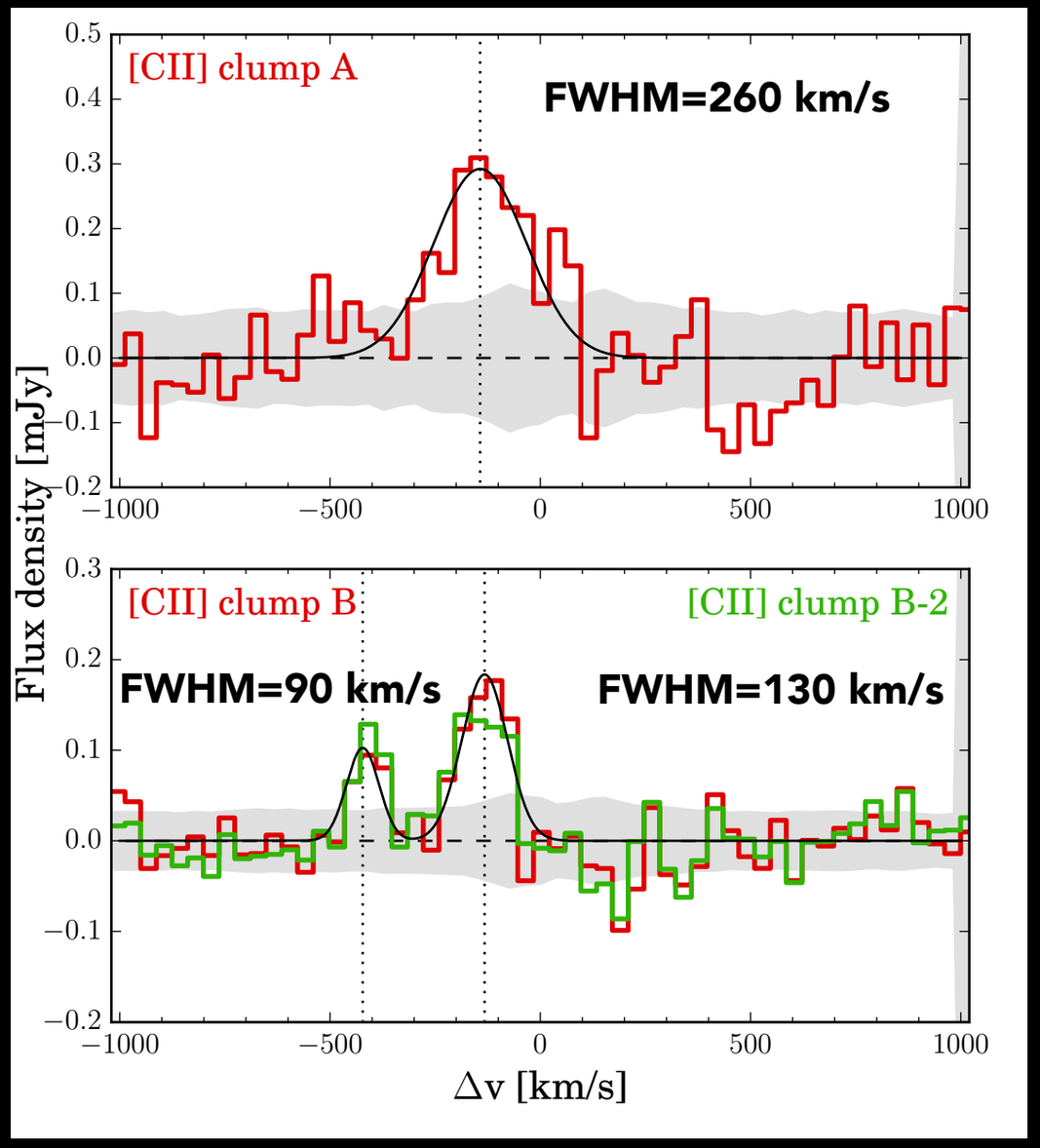


50x50 kpc

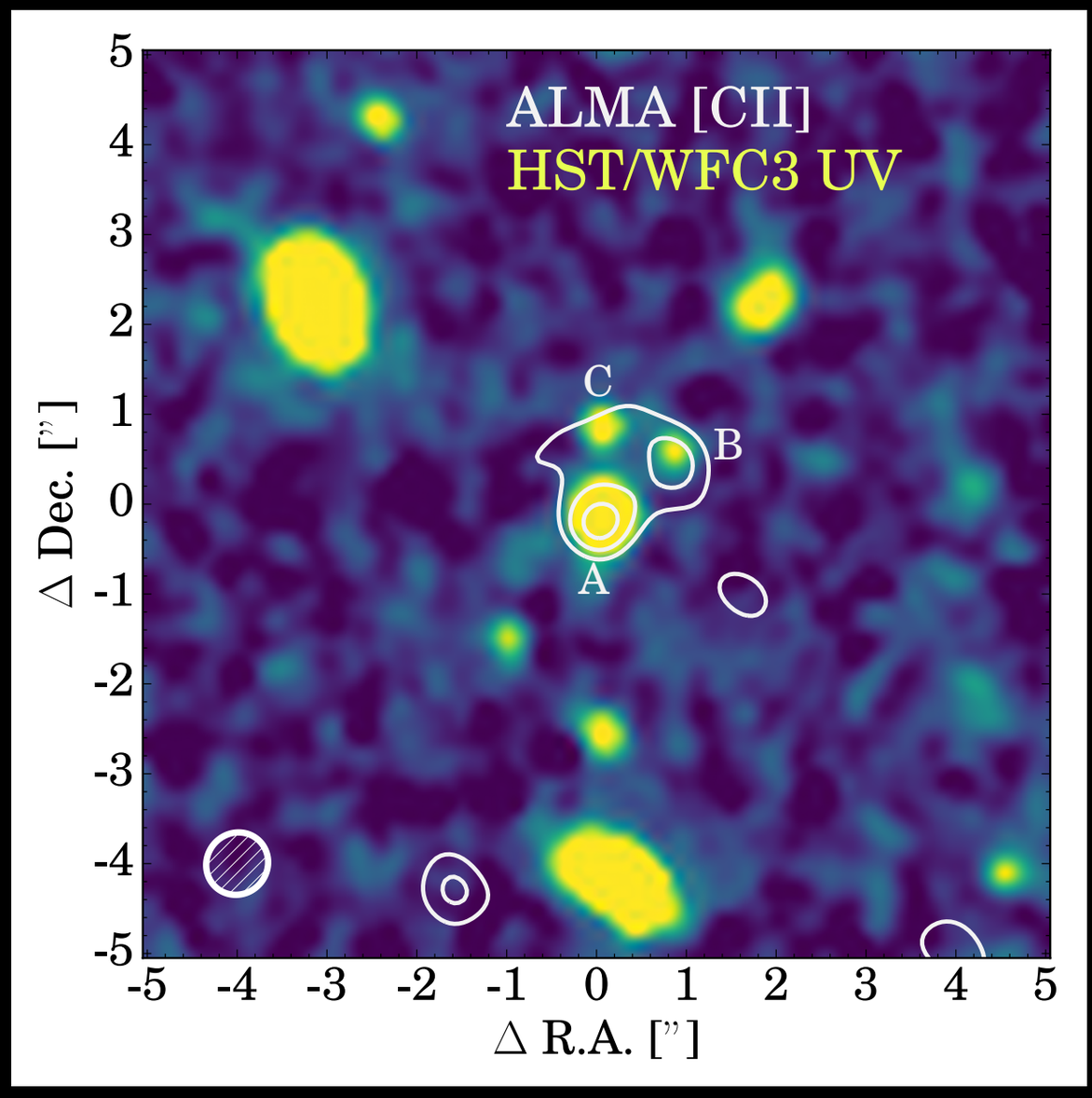
Clear detection of metals through [CII] line-emission -> Z_{gas} ~ 0.1 Z_{sun}

Matthee et al. arXiv:1709.06569

[CII] PROFILES



REST-UV



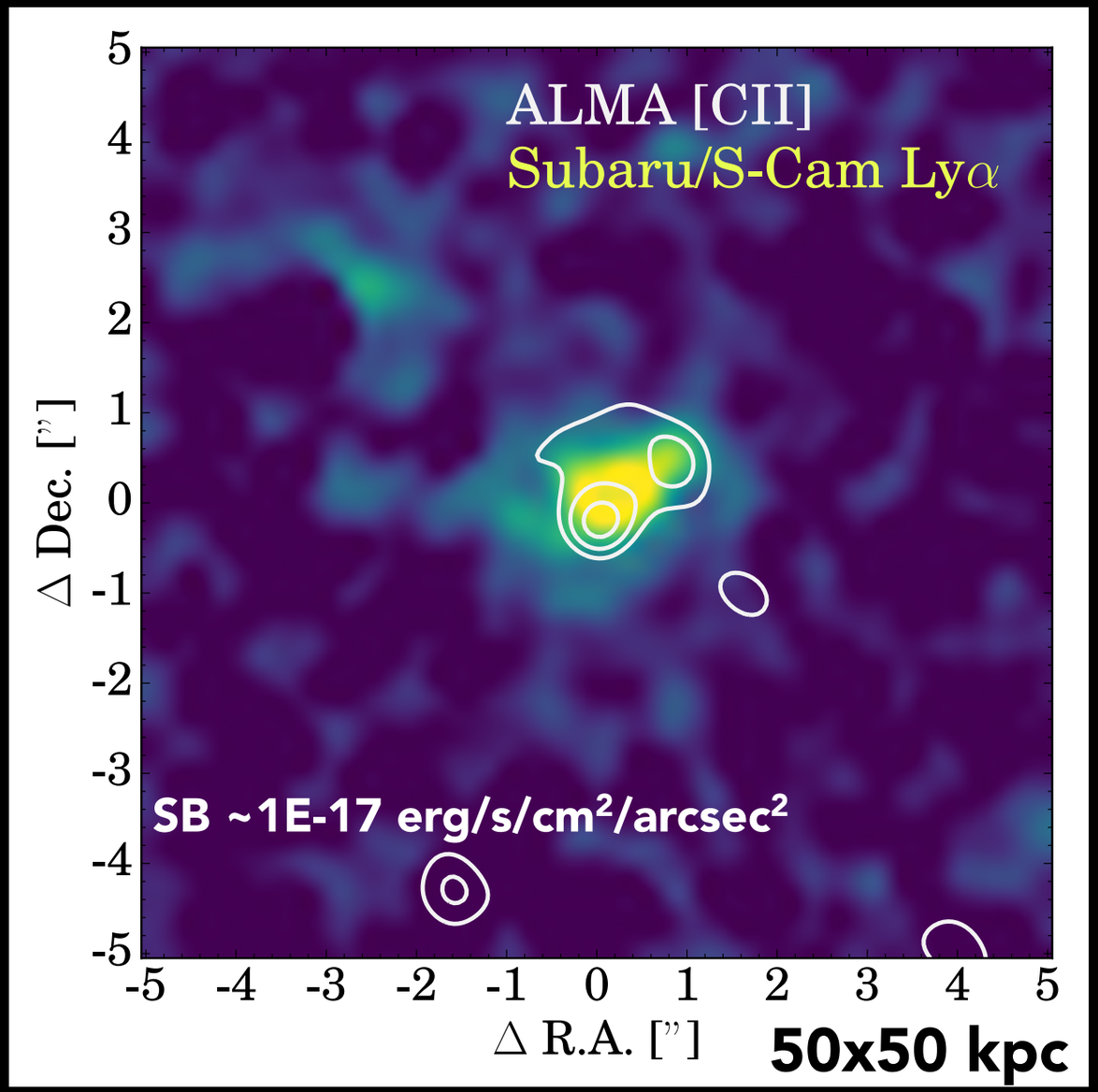
50x50 kpc

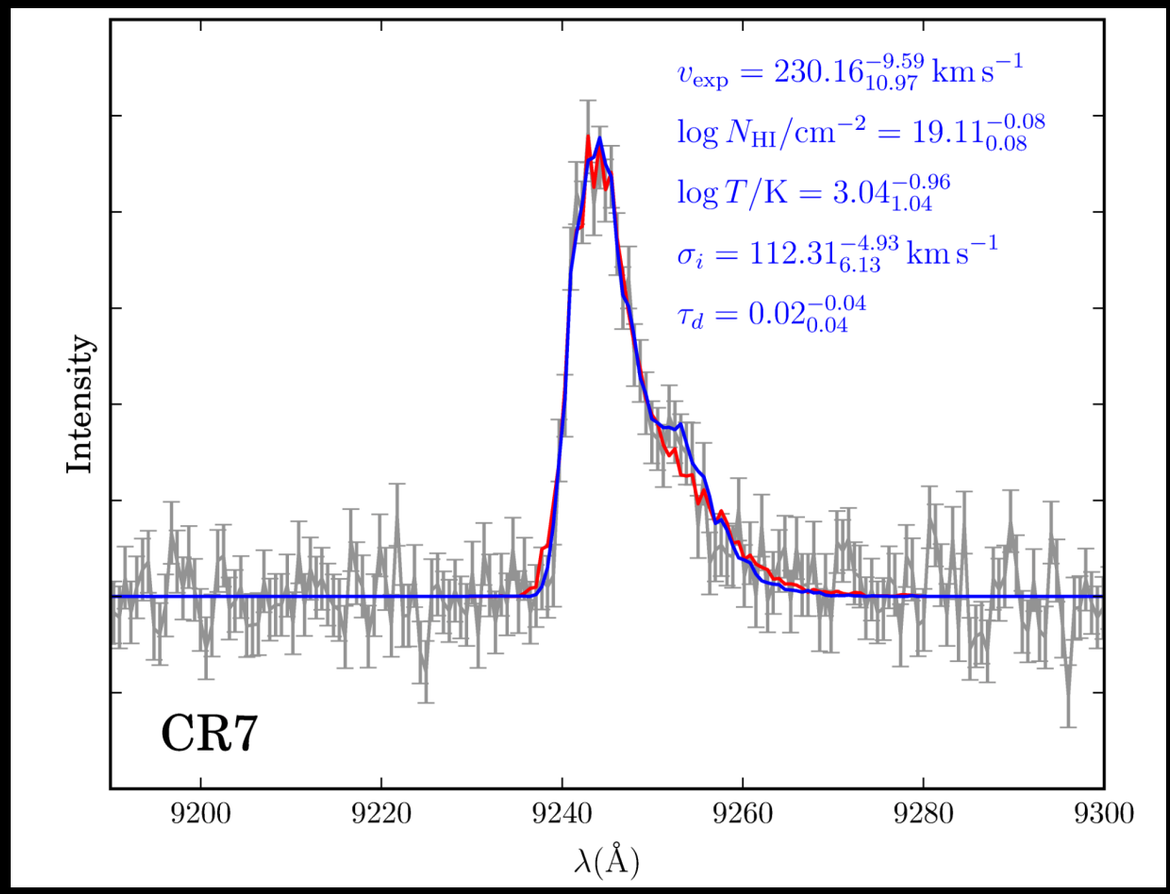
Separate [CII] detections at UV components A & B

Majority of mass likely in A

Matthee et al. arXiv:1709.06569

Relation Lyα - [CII]





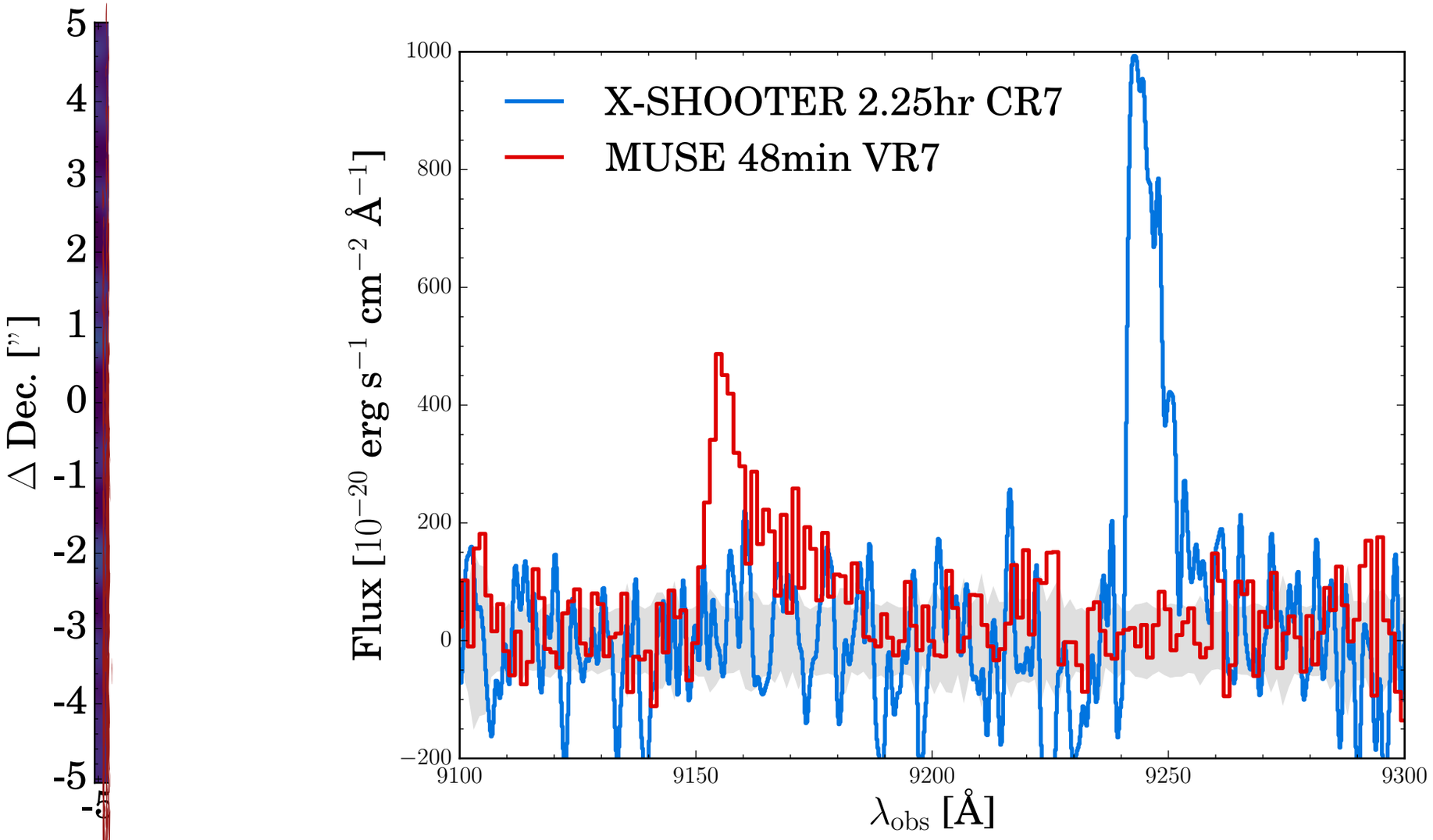
Dijkstra+2016, ApJ, 823, 74

[CII] emission coincides with core of extended Lyα emission

Velocity offset [CII]-Lyα + dispersion agrees well with Lyα shell model

Matthee et al. arXiv:1709.06569

Relation Lyα - [CII]

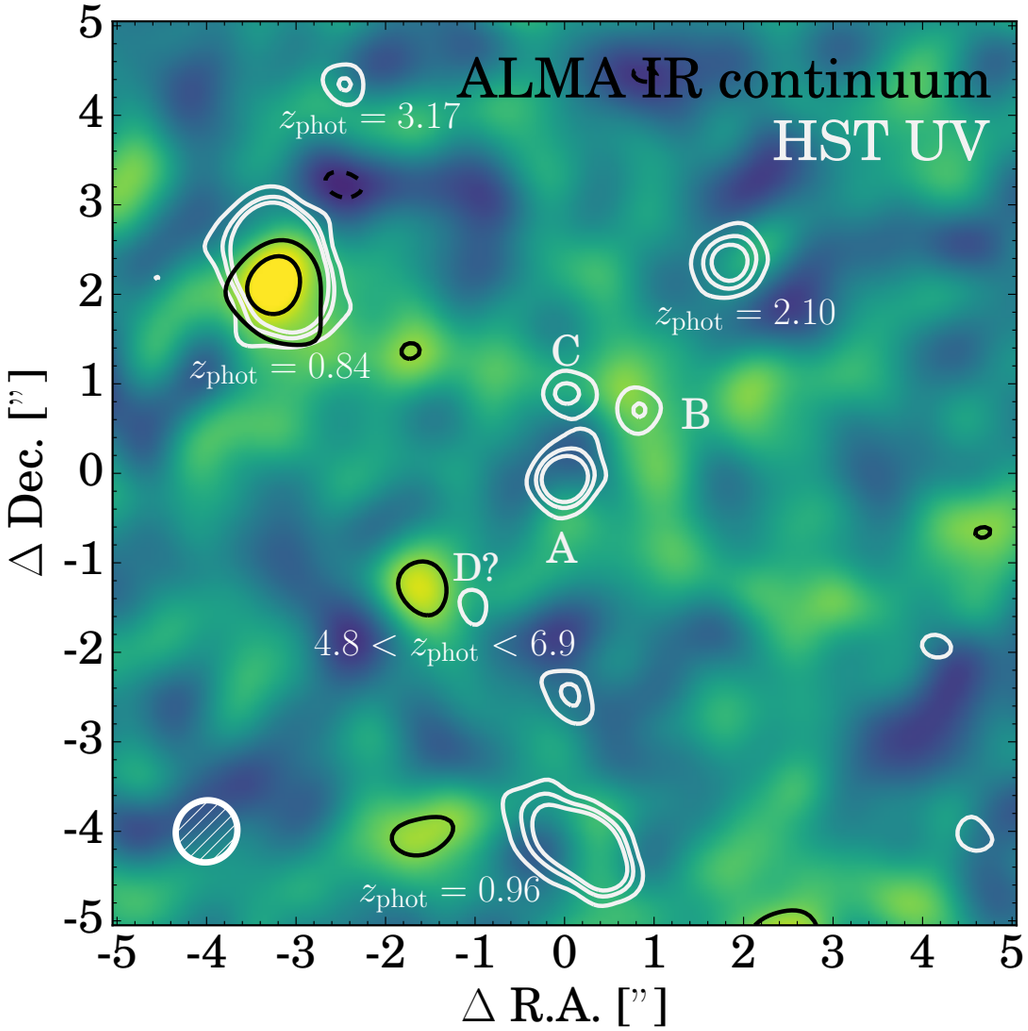


Very promising:

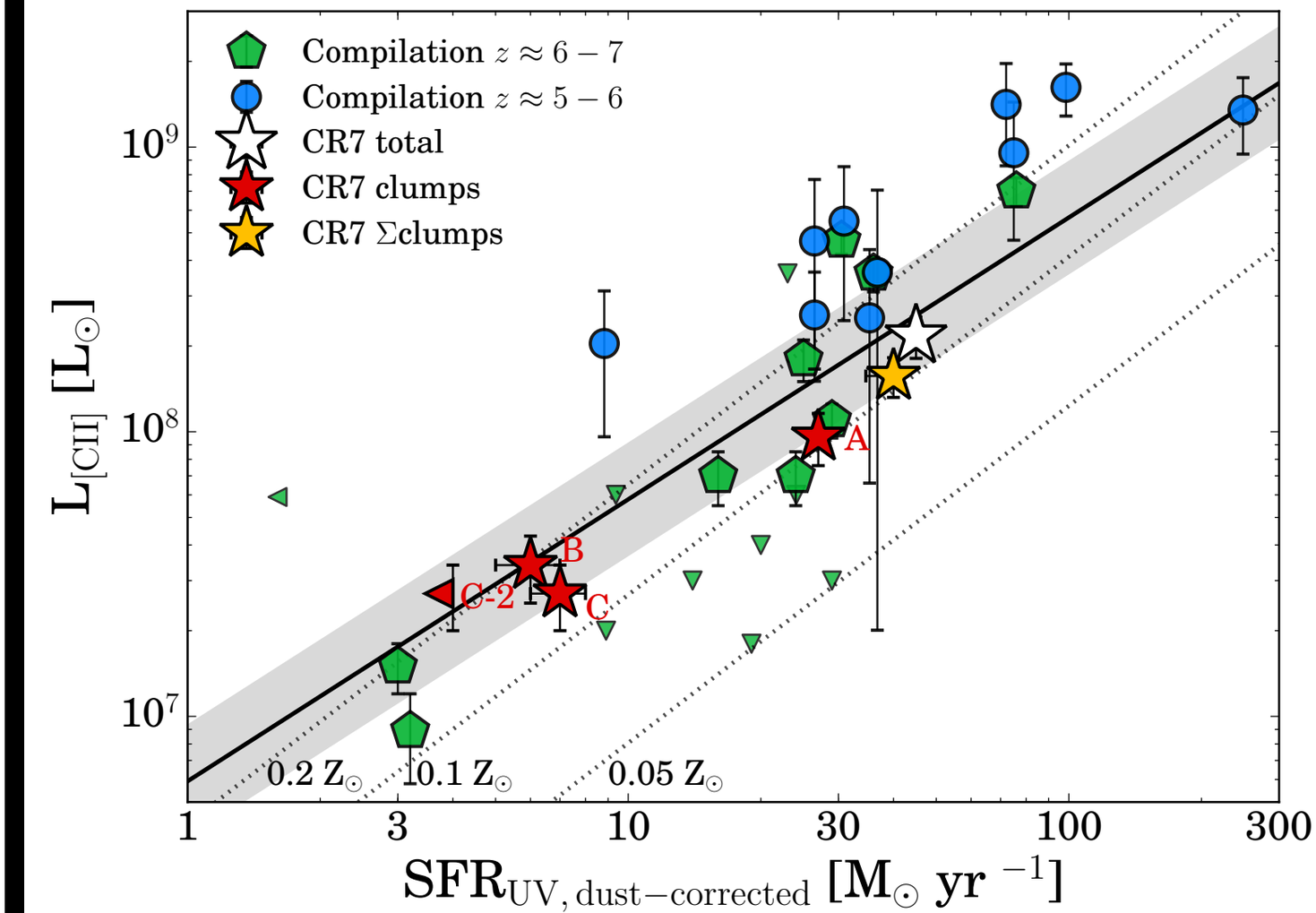
MUSE can easily get Lyα at z=6.5-6.6

Matthee et al. arXiv:1709.06569

DUST CONTINUUM



SFR-[CII] RELATION

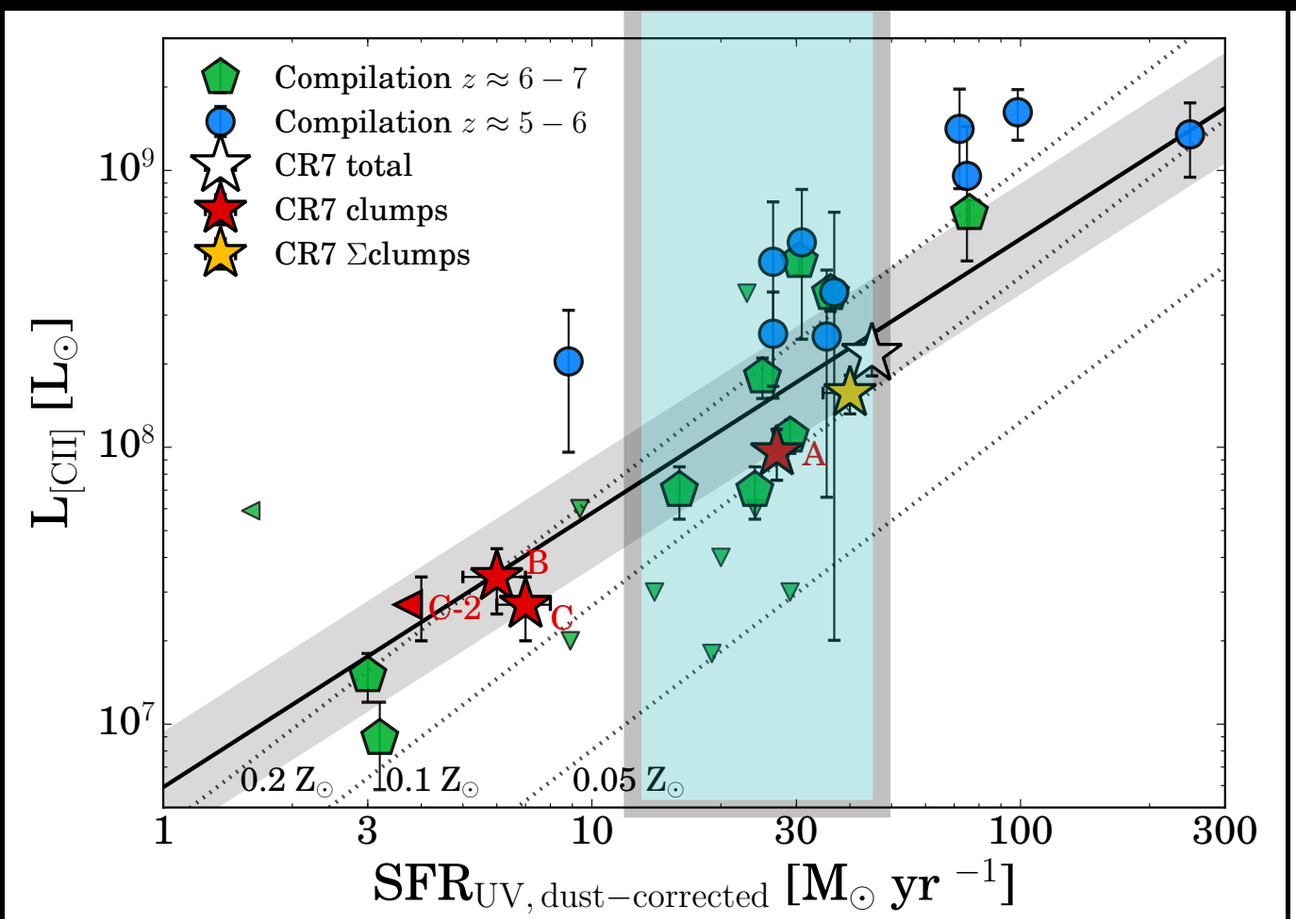


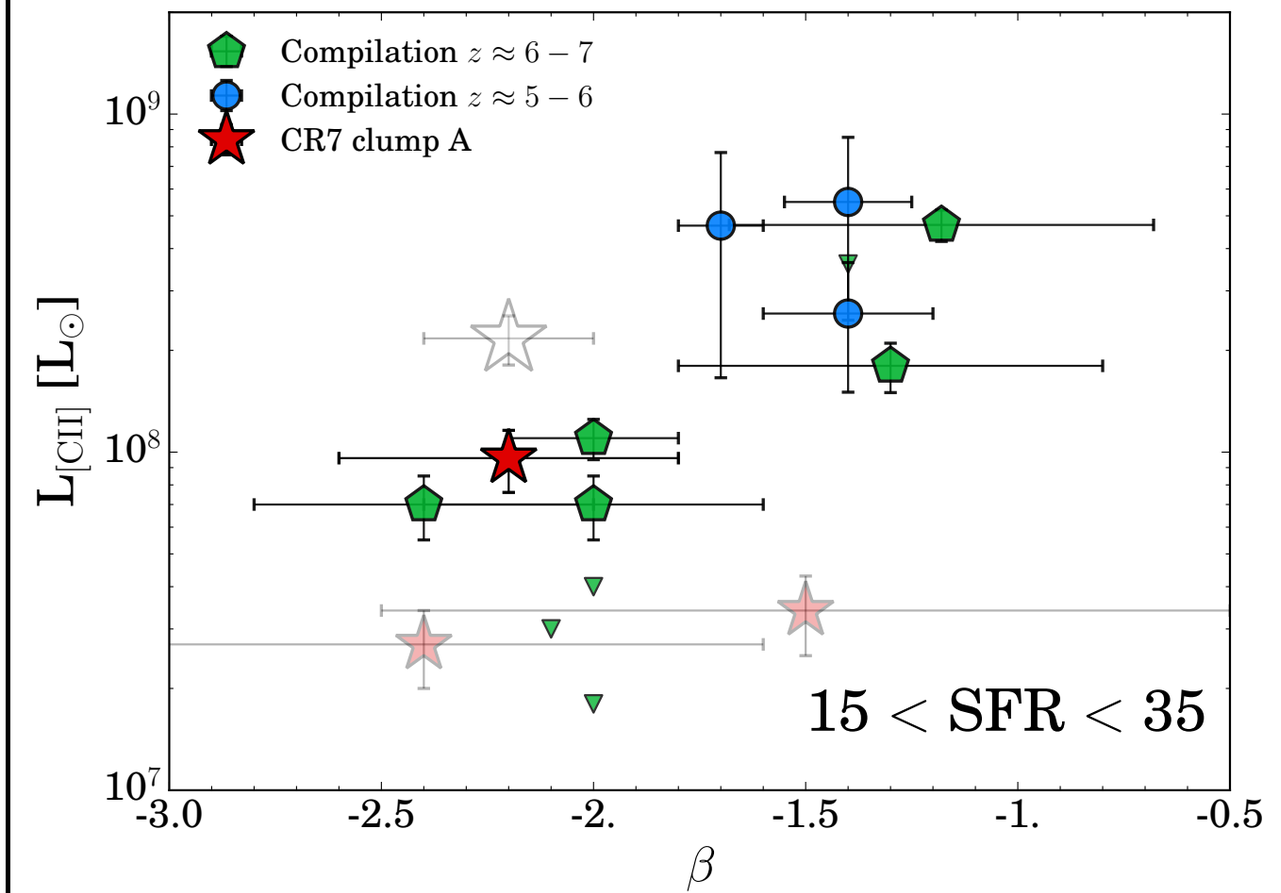
No detection of dust continuum of CR7; rms<7 μJy/beam -> $L_{IR}<3\times10^{10}$ L_{sun} (T_d = 35 K)

[CII]-UV ratio similar to local star-forming galaxies

Matthee et al. arXiv:1709.06569

On offsets in the SFR-[CII] relation



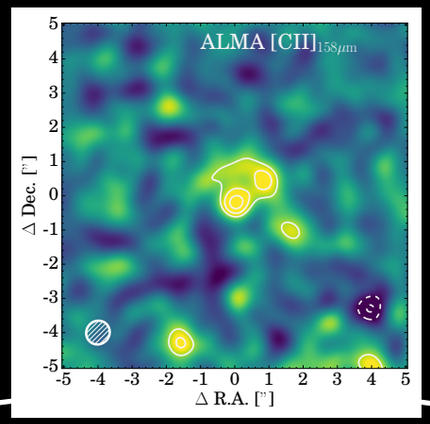


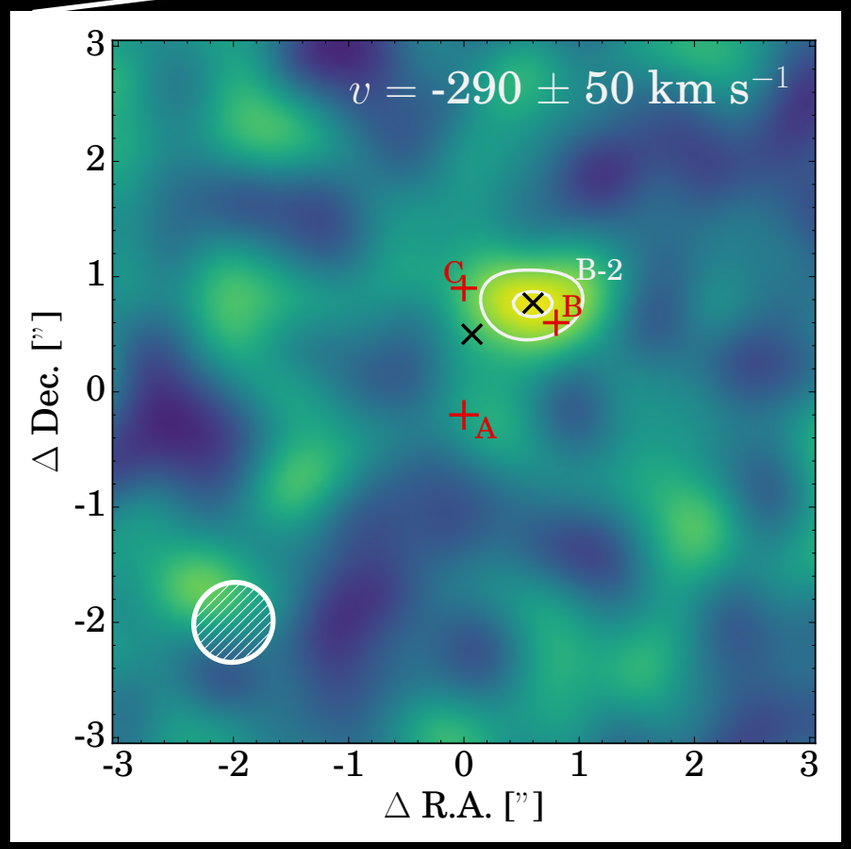
offsets in $L_{[CII]}$-SFR diagram related to UV slope ~age/dust/metallicity

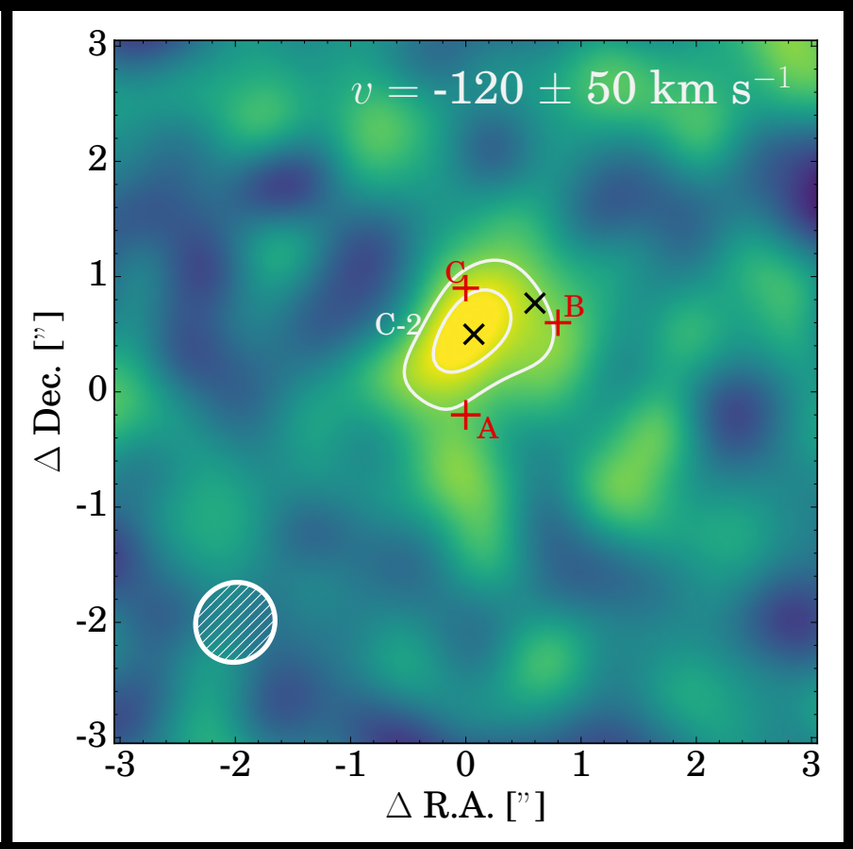
- more fundamental than Lyα in driving offset

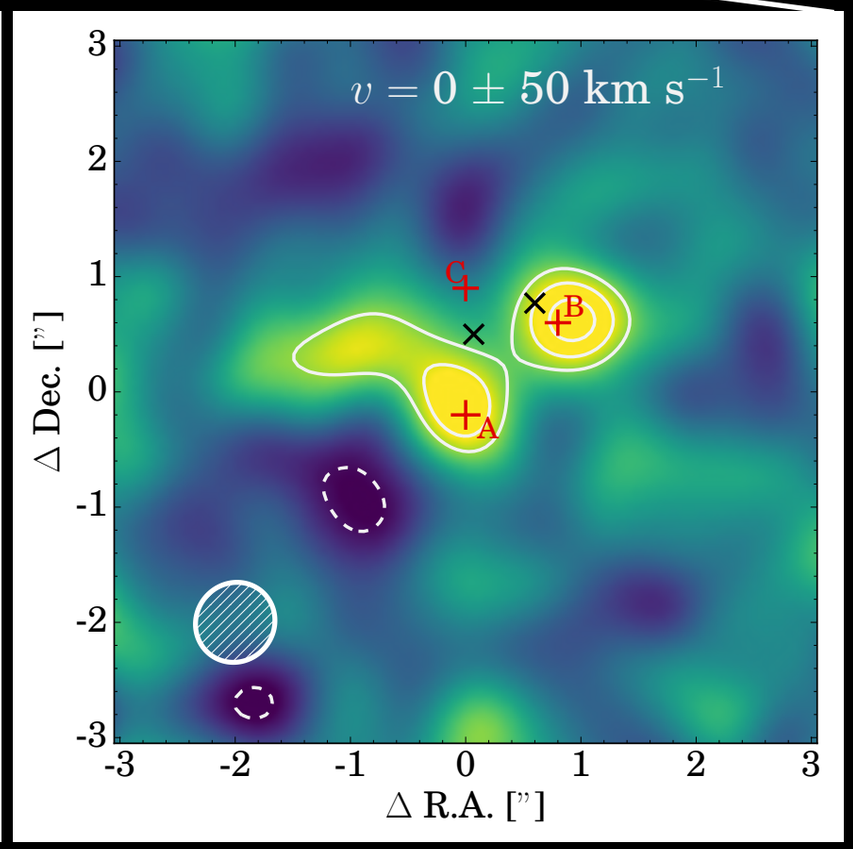
Matthee et al. arXiv:1709.06569

KINEMATICS





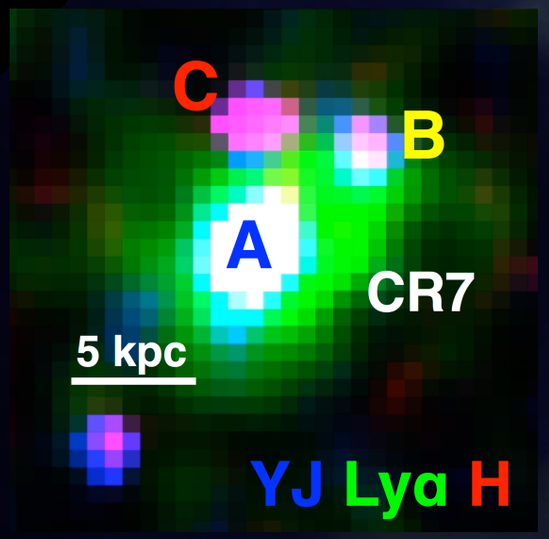




30x30 kpc

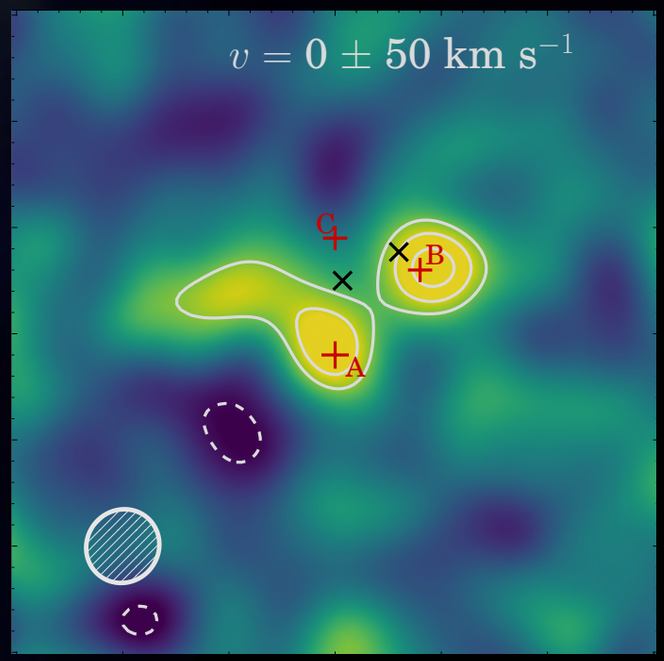
At least 4 distinct [CII] components detected

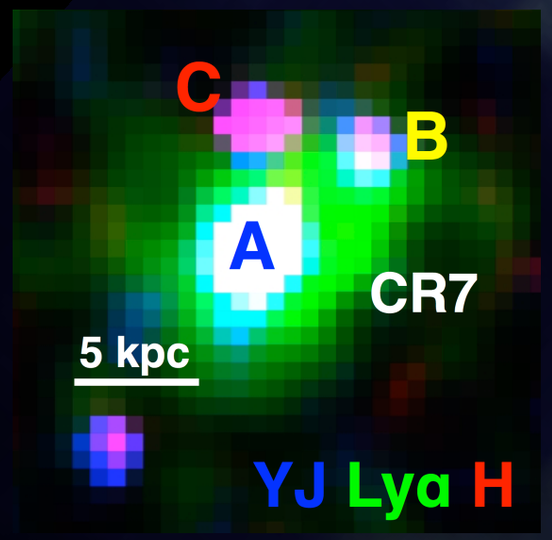
Matthee et al. arXiv:1709.06569



M_{dyn} <7x10^{9} M_{sun}

M_{dyn} ~4x10^{10} M_{sun}

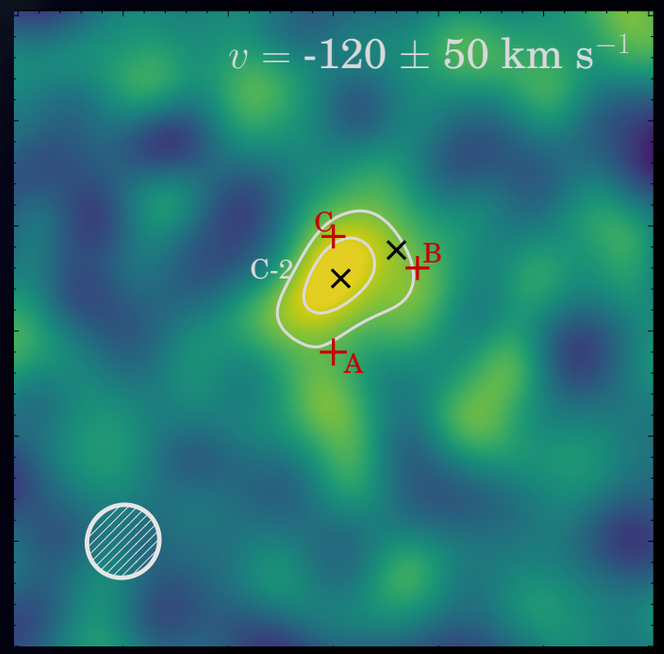


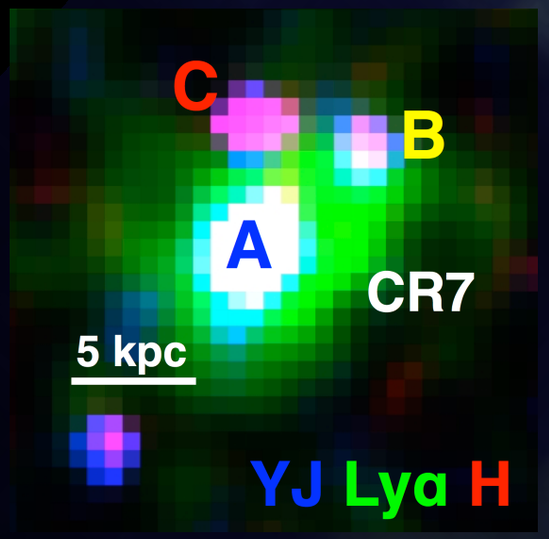


M_{dyn} ~2x10^{10} M_{sun}

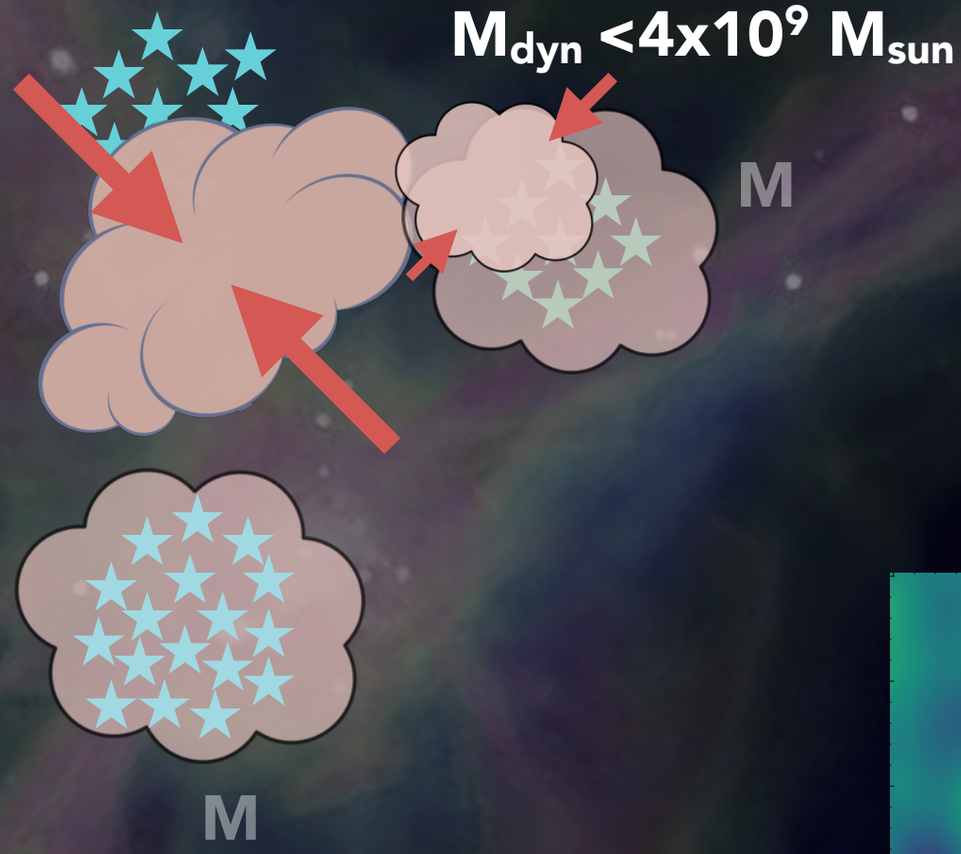
M

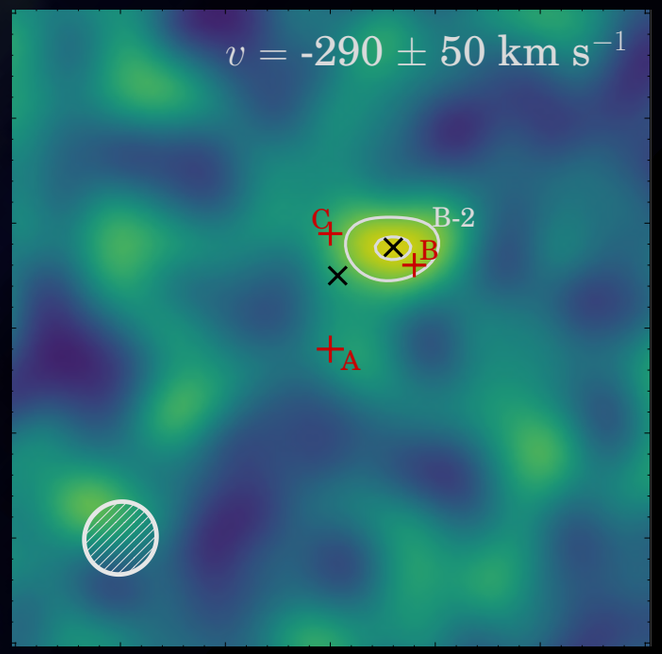
M

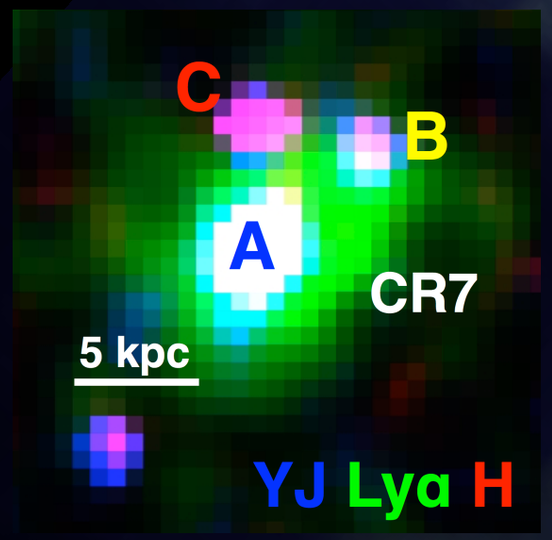


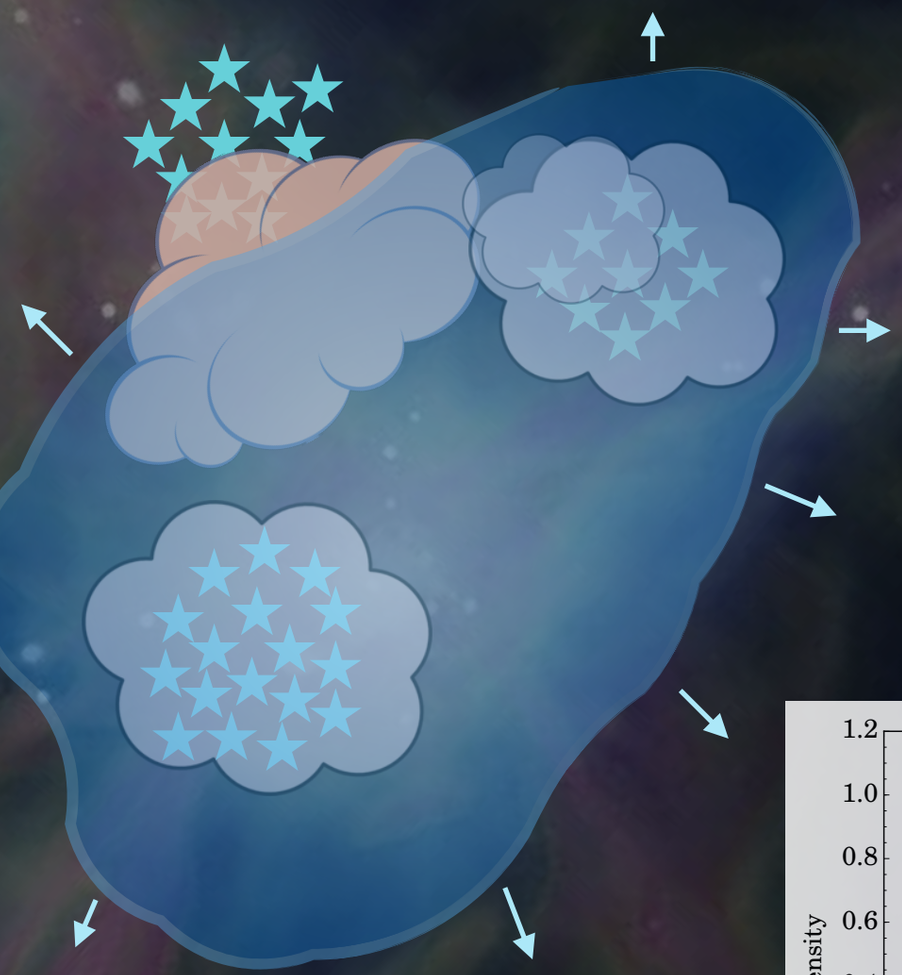


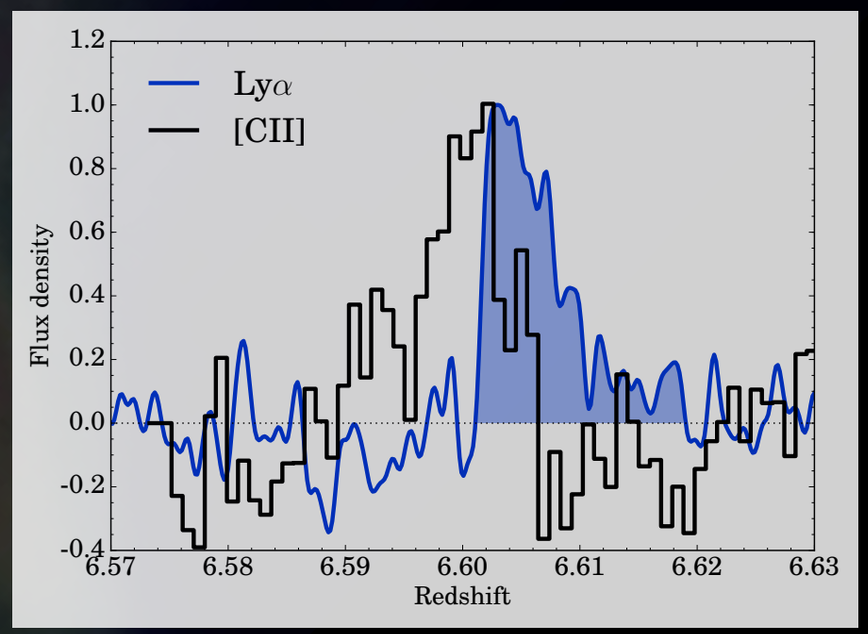
M






C
B
A
CR7
5 kpc
YJ Lyα H




Lyα
[CII]
Flux density
Redshift
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
6.57
6.58
6.59
6.60
6.61
6.62
6.63

SUMMARY

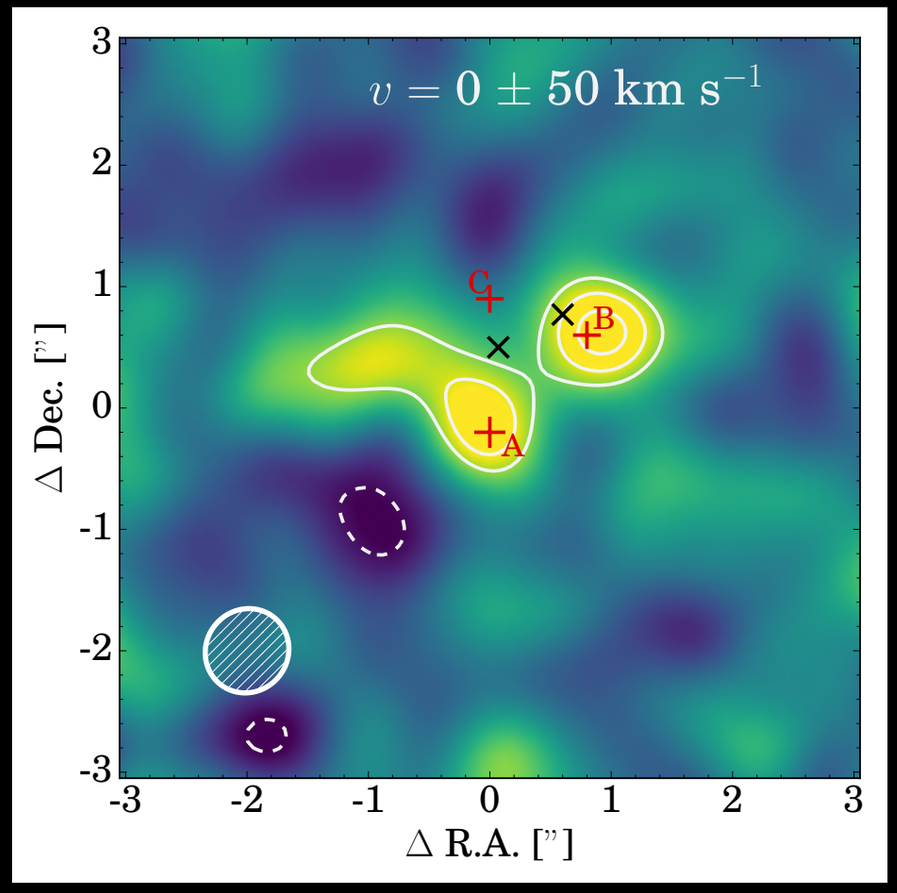
*** At z>6, the number density of faint Lyα emitters decreases more rapidly than the number density of bright galaxies (reionization?)**

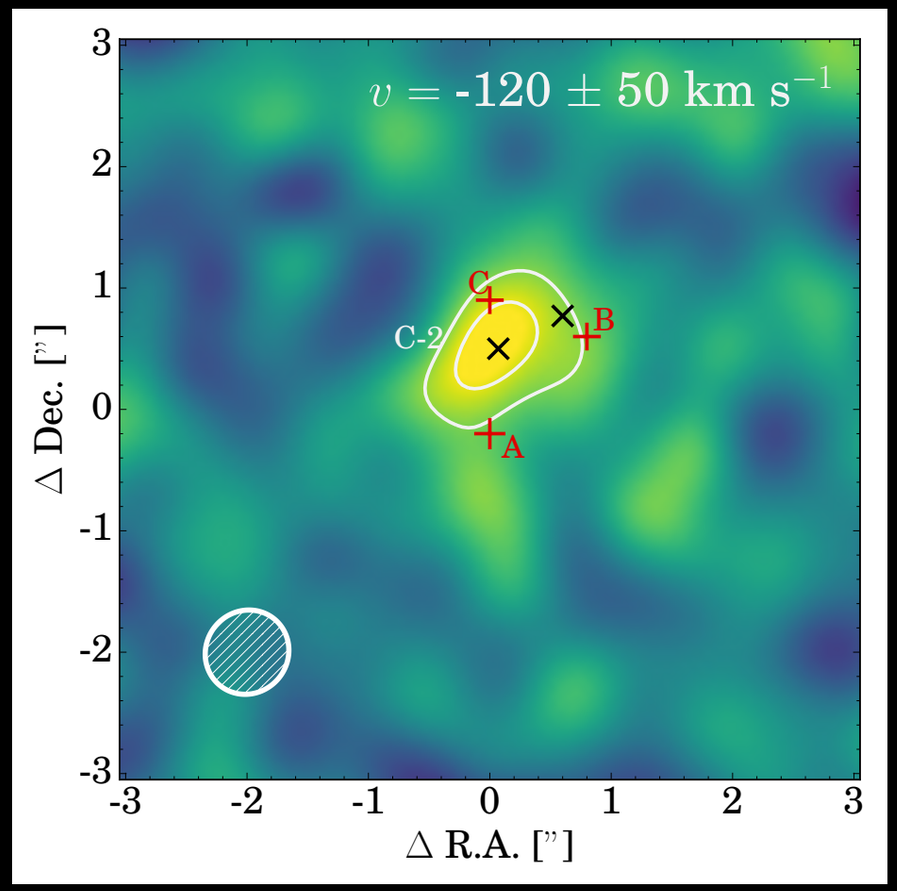
*** Many luminous z~6-7 galaxies have multiple-components: require spatially resolved spectroscopy (IFU)**

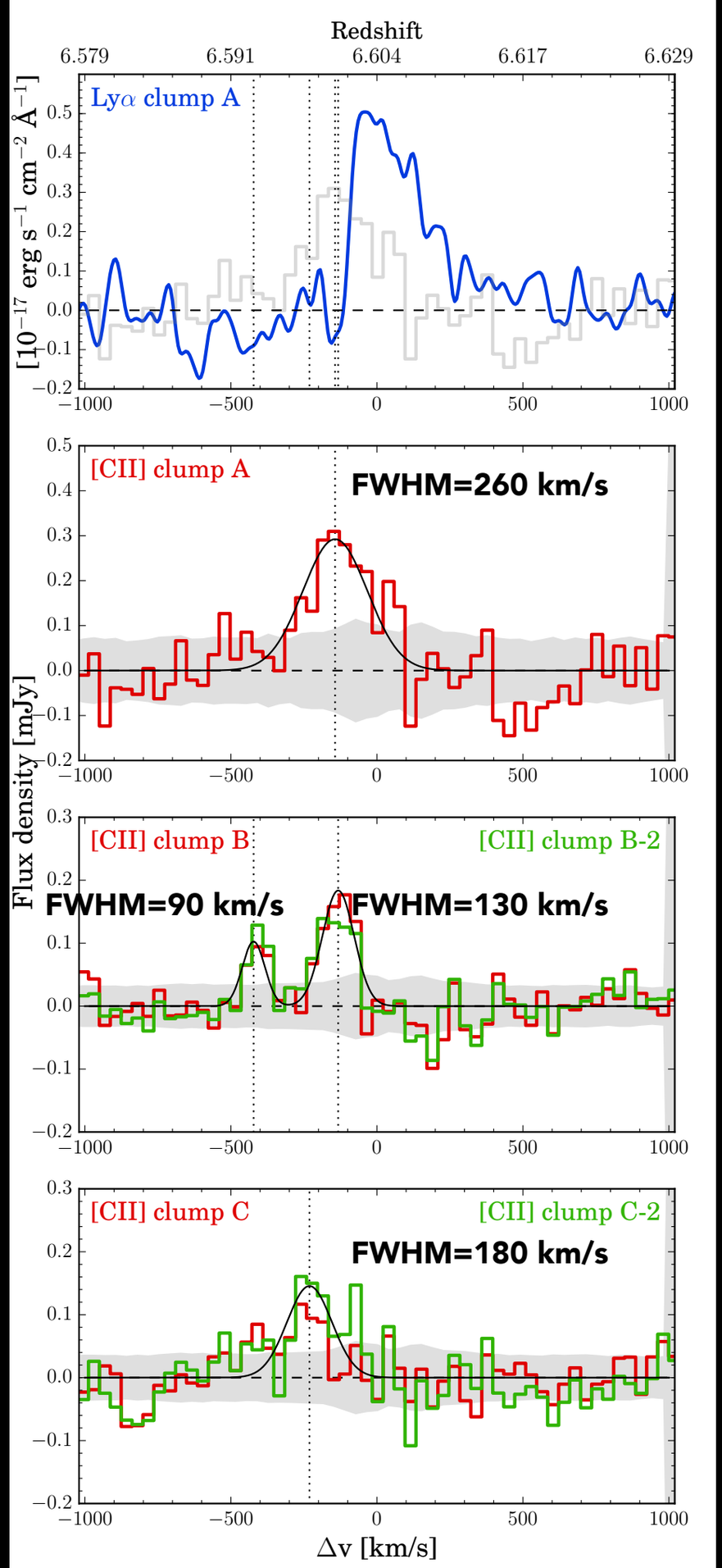
*** CR7 contains metals, with similar [CII]-UV ratio as local SFGs, and the light is *not* dominated by a primordial object (PopIII-like/DCBH)**

*** CR7 is a complex system, likely undergoing a major merger with accreting clumps/satellites with an outflowing shell of HI gas indicating feedback is already in place in the early Universe**

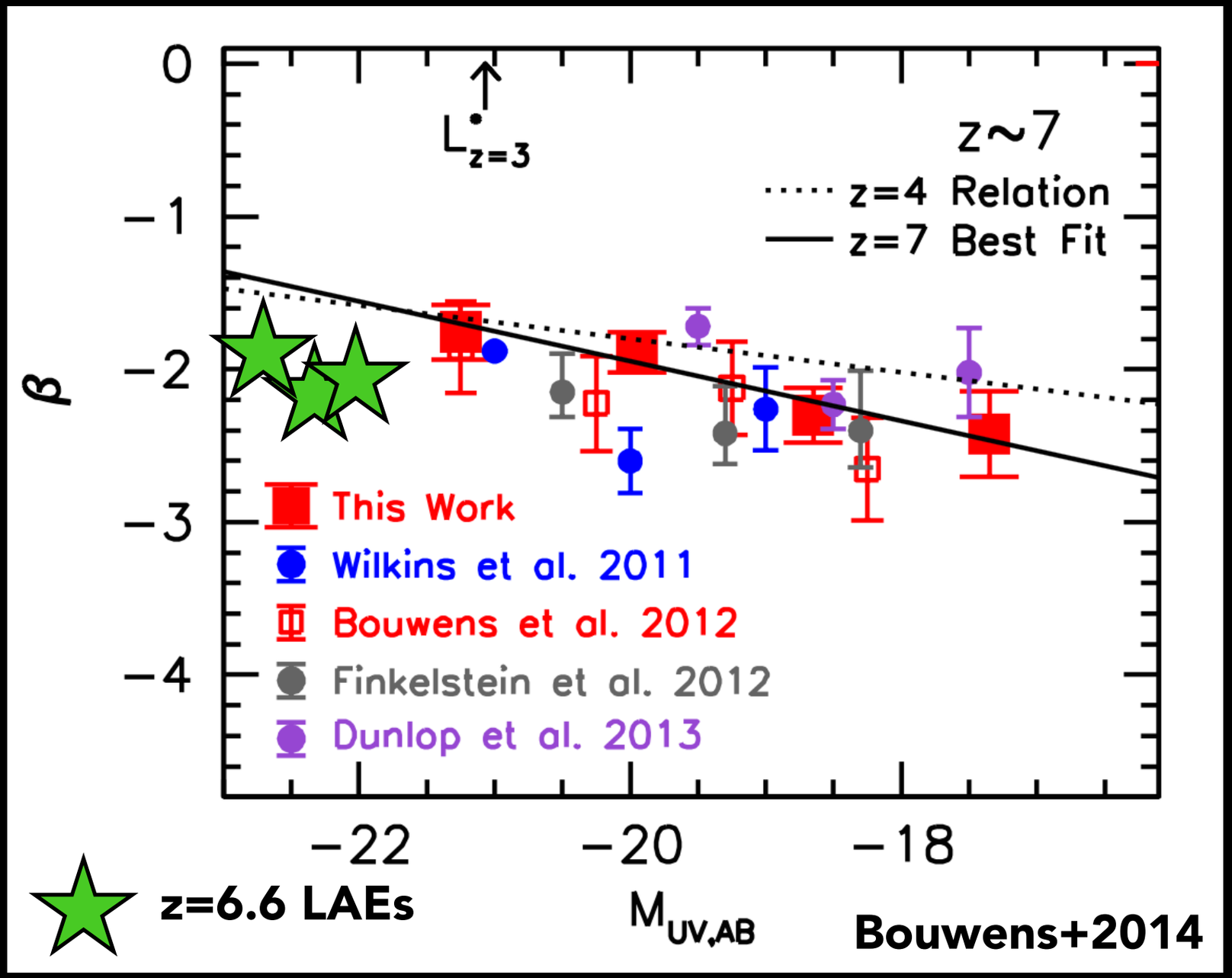
Luminosity function: Matthee+2015, MNRAS, 451, 400; Santos+2016, MNRAS, 463, 1678
Spectroscopy/HST imaging: Matthee+2017, MNRAS, 472, 772; Sobral+2015, ApJ, 808, 139
ξ_{ion} model: Matthee+2017, 465, 3637
ALMA: Matthee+2017, arXiv: 1709.06569


$v = 0 \pm 50$ km s^{-1}
C
B
A
Δ Dec. ["]
Δ R.A. ["]

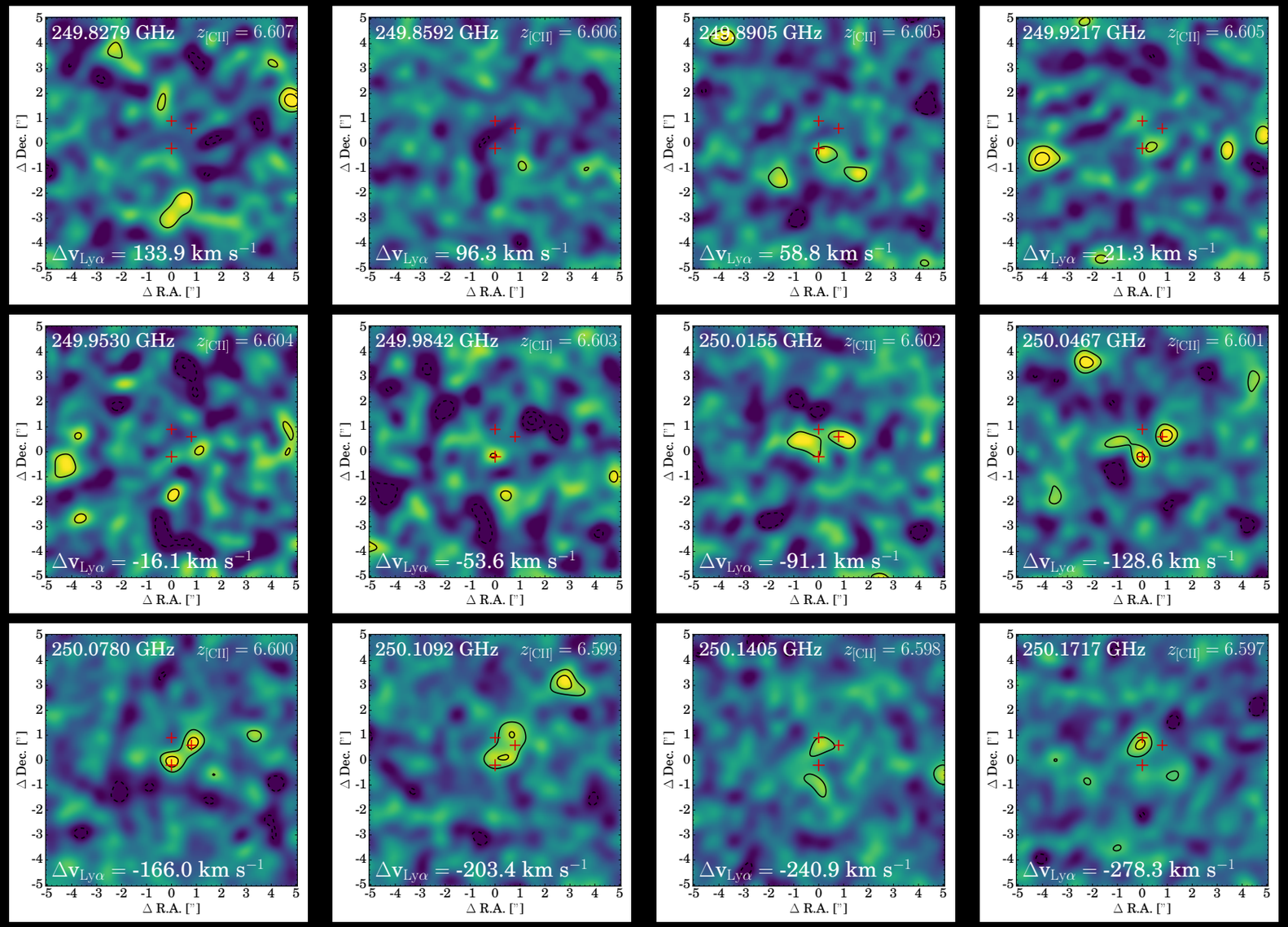

v = -120 ± 50 km s^{-1}
C
C-2
B
A
Δ Dec. ["]
Δ R.A. ["]


Redshift
Lyα clump A
[CII] clump A
FWHM=260 km/s
[CII] clump B
[CII] clump B-2
FWHM=90 km/s
FWHM=130 km/s
[CII] clump C
[CII] clump C-2
FWHM=180 km/s
Flux density
Δv [km/s]

At fixed UV luminosity, bright LAEs are bluer



Matthee+2017c, MNRAS, 472, 772


249.8279 GHz $z_{[CII]} = 6.607$ $\Delta v_{Ly\alpha} = 133.9$ km s^{-1}
249.8592 GHz $z_{[CII]} = 6.606$ $\Delta v_{Ly\alpha} = 96.3$ km s^{-1}
249.8905 GHz $z_{[CII]} = 6.605$ $\Delta v_{Ly\alpha} = 58.8$ km s^{-1}
249.9217 GHz $z_{[CII]} = 6.605$ $\Delta v_{Ly\alpha} = 21.3$ km s^{-1}
249.9530 GHz $z_{[CII]} = 6.604$ $\Delta v_{Ly\alpha} = -16.1$ km s^{-1}
249.9842 GHz $z_{[CII]} = 6.603$ $\Delta v_{Ly\alpha} = -53.6$ km s^{-1}
250.0155 GHz $z_{[CII]} = 6.602$ $\Delta v_{Ly\alpha} = -91.1$ km s^{-1}
250.0467 GHz $z_{[CII]} = 6.601$ $\Delta v_{Ly\alpha} = -128.6$ km s^{-1}
250.0780 GHz $z_{[CII]} = 6.600$ $\Delta v_{Ly\alpha} = -166.0$ km s^{-1}
250.1092 GHz $z_{[CII]} = 6.599$ $\Delta v_{Ly\alpha} = -203.4$ km s^{-1}
250.1405 GHz $z_{[CII]} = 6.598$ $\Delta v_{Ly\alpha} = -240.9$ km s^{-1}
250.1717 GHz $z_{[CII]} = 6.597$ $\Delta v_{Ly\alpha} = -278.3$ km s^{-1}
250.2030 GHz $z_{[CII]} = 6.596$ $\Delta v_{Ly\alpha} = -315.7$ km s^{-1}
250.2343 GHz $z_{[CII]} = 6.595$ $\Delta v_{Ly\alpha} = -353.1$ km s^{-1}
250.2655 GHz $z_{[CII]} = 6.594$ $\Delta v_{Ly\alpha} = -390.5$ km s^{-1}
250.2968 GHz $z_{[CII]} = 6.593$ $\Delta v_{Ly\alpha} = -427.9$ km s^{-1}
250.3280 GHz $z_{[CII]} = 6.592$ $\Delta v_{Ly\alpha} = -465.3$ km s^{-1}
250.3593 GHz $z_{[CII]} = 6.591$ $\Delta v_{Ly\alpha} = -502.6$ km s^{-1}
250.3905 GHz $z_{[CII]} = 6.590$ $\Delta v_{Ly\alpha} = -540.0$ km s^{-1}
250.4218 GHz $z_{[CII]} = 6.589$ $\Delta v_{Ly\alpha} = -577.3$ km s^{-1}
Δ R.A. ["]
Δ Dec. ["]

TOY MODEL FOR LYA LF EVOLUTION DUE TO RE-IONISATION

Input parameters:

- Escape fraction Lya = 30%, case B recombination
- Escape fraction LyC = 5%
- age Lya = 100 Myr
- Salpeter IMF, max M = 100 Msun

$$L(H\alpha) = 8.6 f_{esc,Ly\alpha} L(Ly\alpha) \ \text{erg s}^{-1}$$

$$N_{\gamma,em} = \frac{L(H\alpha)}{1.37 \times 10^{-12}} \ \text{s}^{-1}$$

$$R_S = 4.3\, x_{\text{IGM}}^{-1/3} \left(\frac{f_{esc,ion} N_{\gamma,em}}{1.3 \times 10^{57} \text{s}^{-1}}\right)^{1/3} \left(\frac{t}{2 \times 10^{7} \text{yr}}\right)^{1/3} \text{Mpc}$$

Matthee et al. 2015, MNRAS, 451, 400 (arXiv:1502.07355)