DISCOVERY OF THE BRIGHTEST LYMAN-ALPHA EMITTERS IN THE EPOCH OF RE-IONISATION

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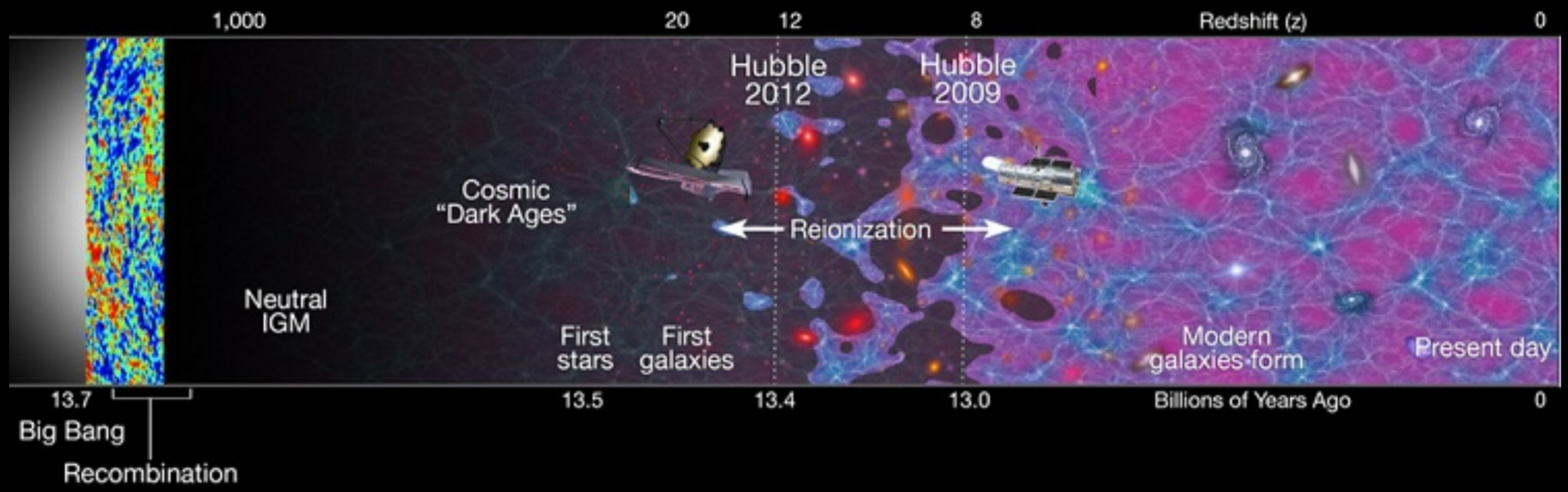
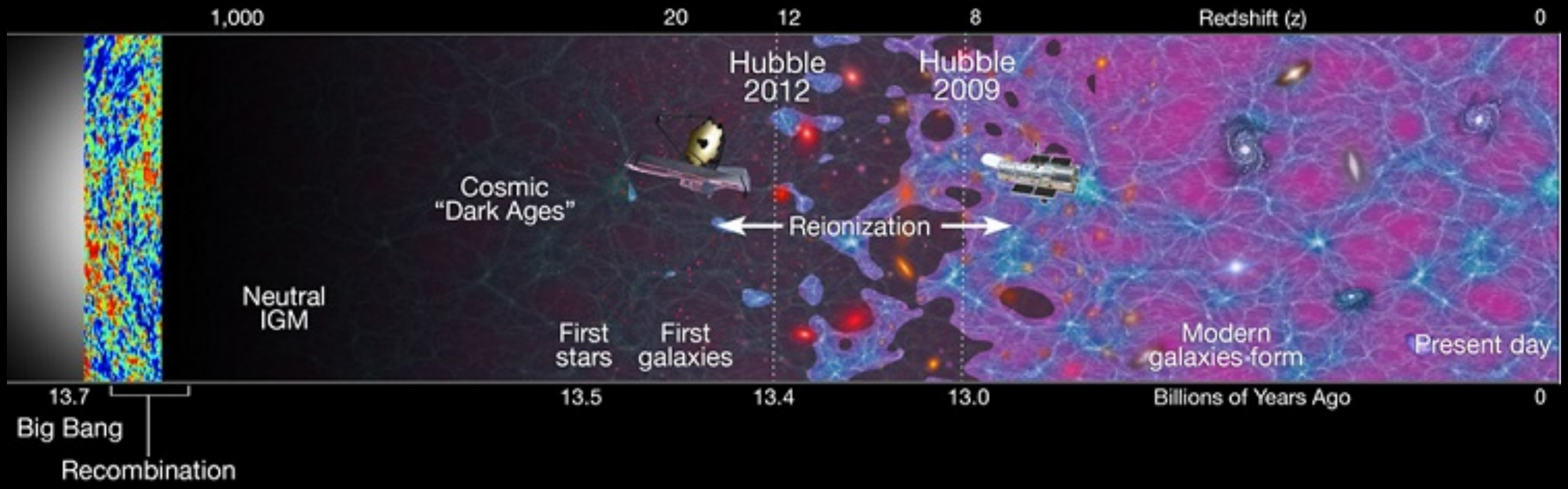
Subaru Telescope, National Astronomical Observatory of Japan



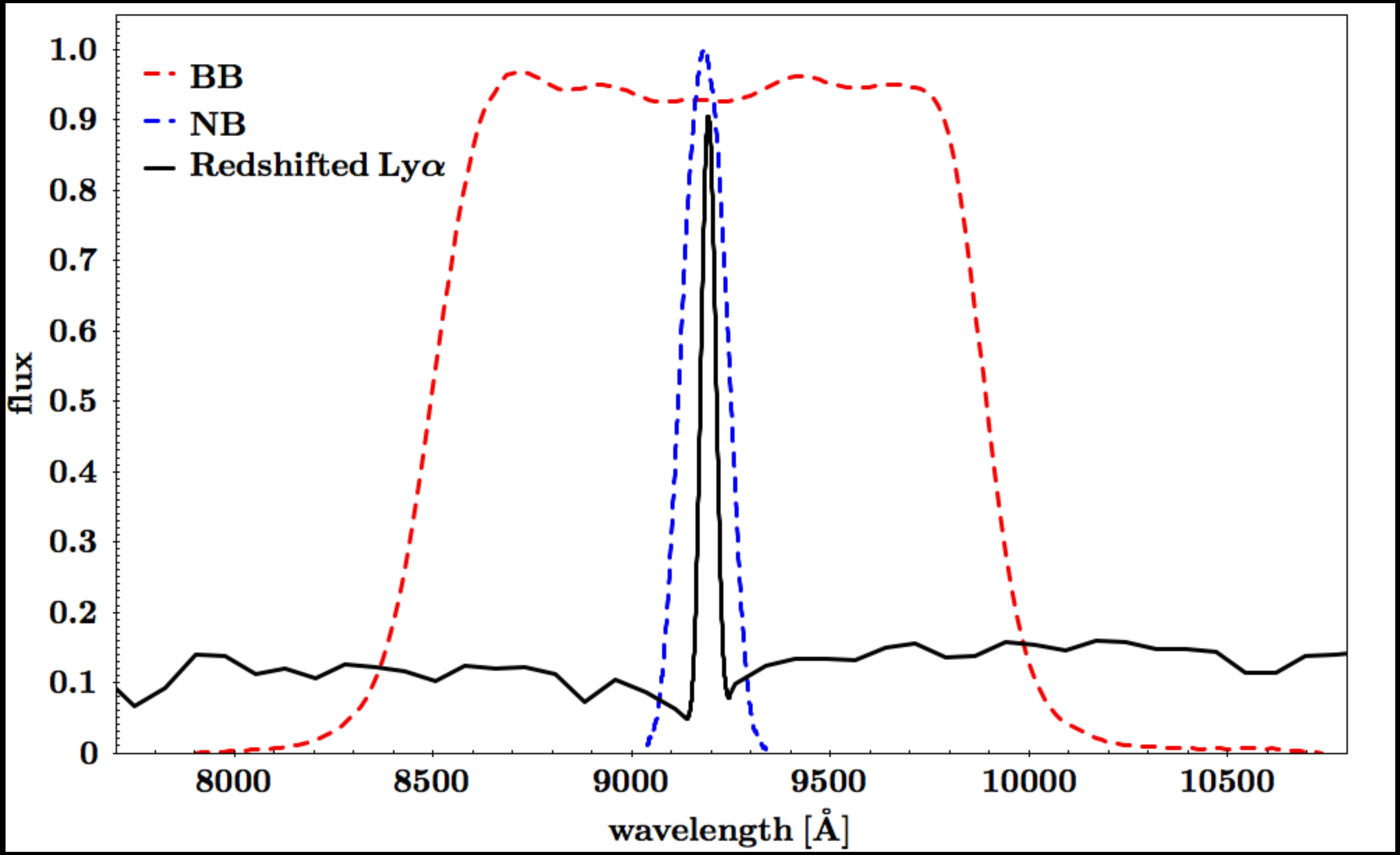
- When and how did the first stars and galaxies form?
- When and how did re-ionisation happen?

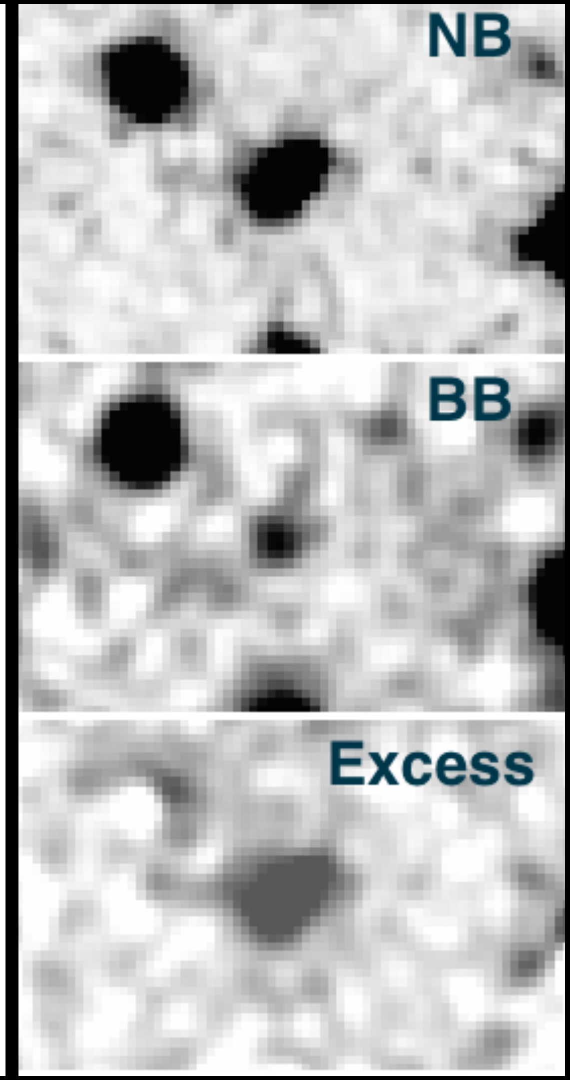


- When and how did the first stars and galaxies form?
- When and how did re-ionisation happen?
- How do we observe the first galaxies and their interaction with re-ionisation?

LYMAN-ALPHA AS A TOOL TO STUDY YOUNG GALAXIES AND RE-IONISATION

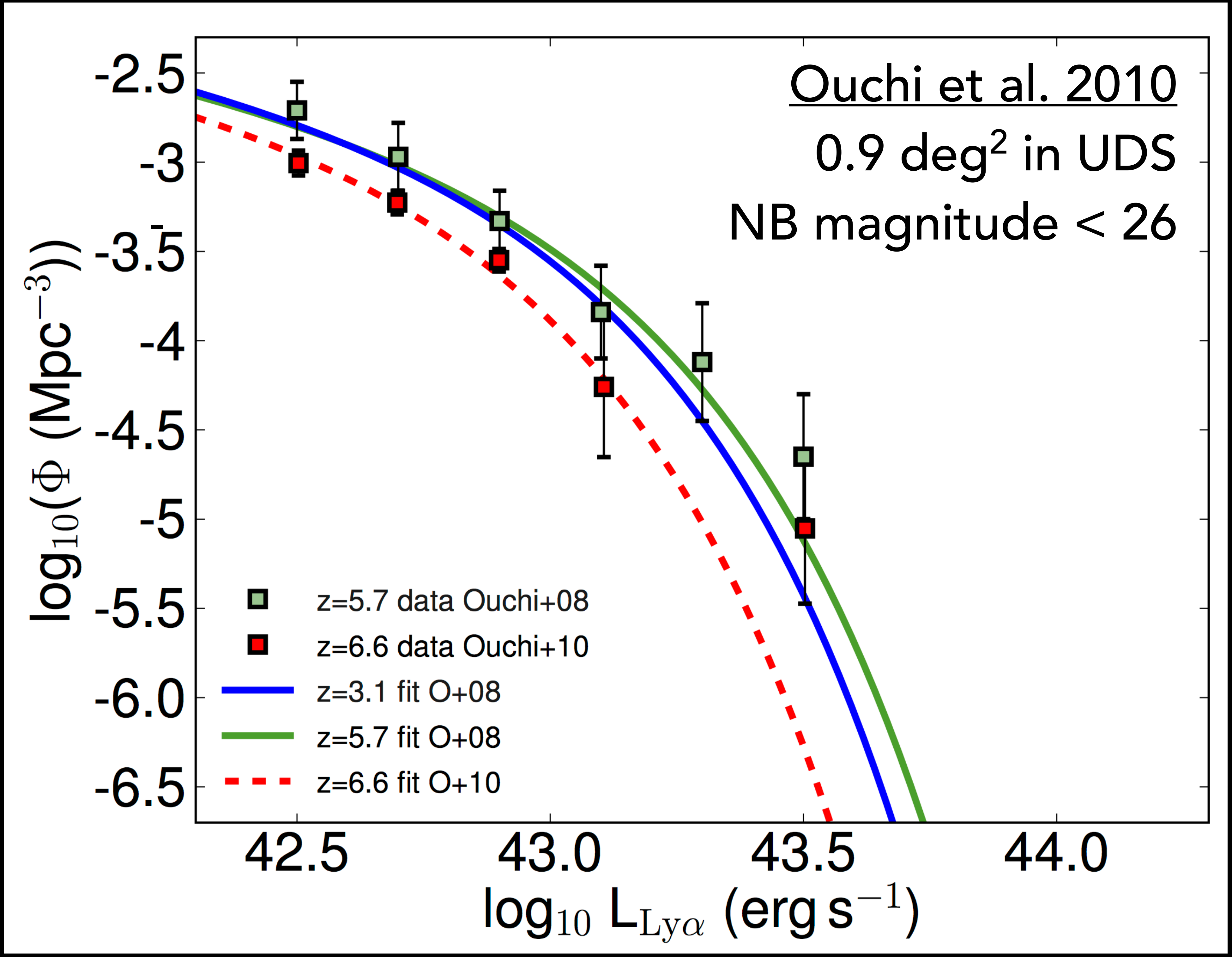
- narrow-band selects redshifted 1216 Å (optical at z>2)





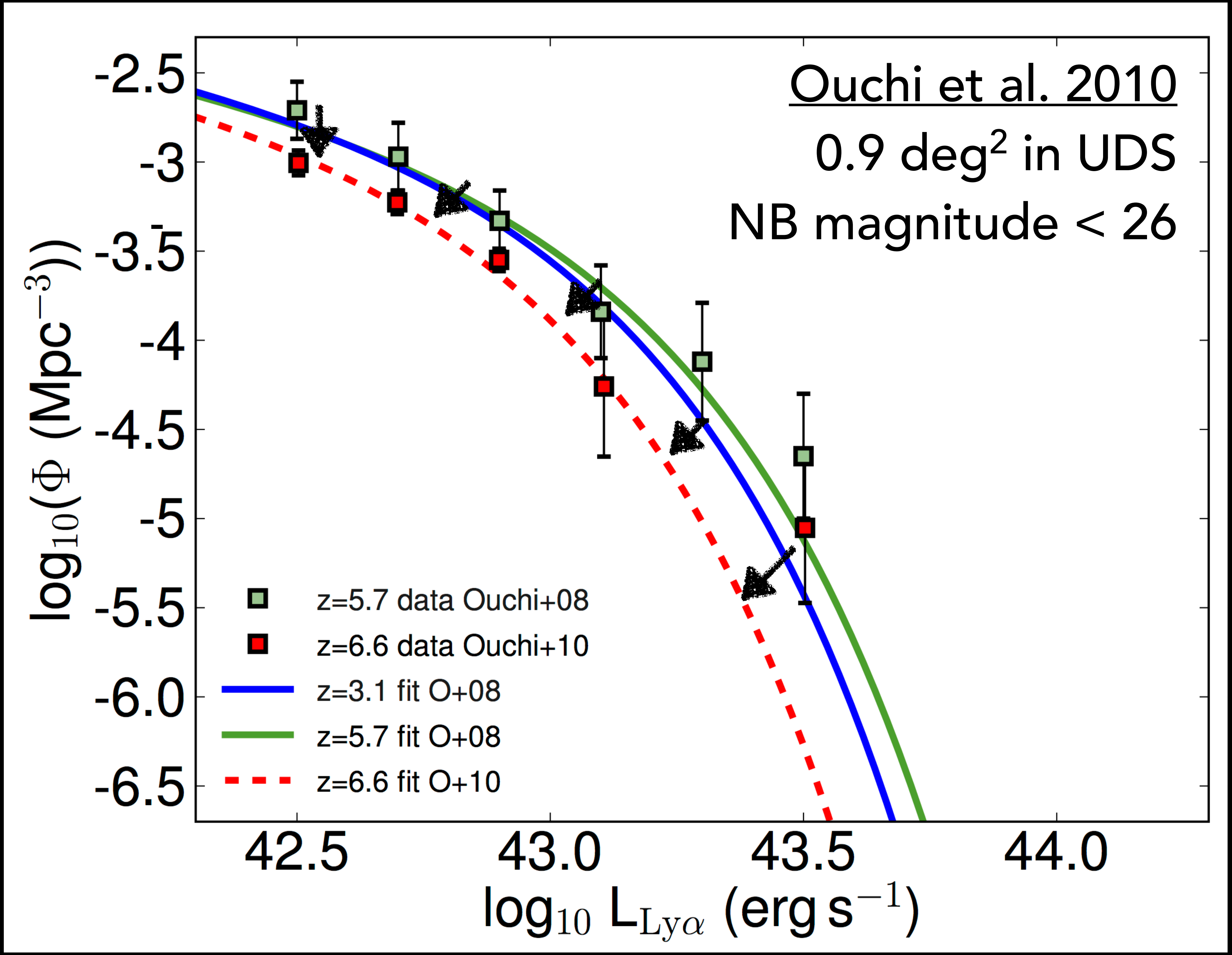
- Lyα emitted by young galaxies (high EW)
- Lyα absorbed in more neutral IGM (test for re-ionisation)

LYA AT Z=6.6


Ouchi et al. 2010
0.9 deg^2 in UDS
NB magnitude < 26
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6.0
-6.5
$\log_{10}(\Phi\ (\mathrm{Mpc}^{-3}))$
42.5
43.0
43.5
44.0
$\log_{10} L_{\mathrm{Ly}\alpha}\ (\mathrm{erg\,s^{-1}})$
z=5.7 data Ouchi+08
z=6.6 data Ouchi+10
z=3.1 fit O+08
z=5.7 fit O+08
z=6.6 fit O+10

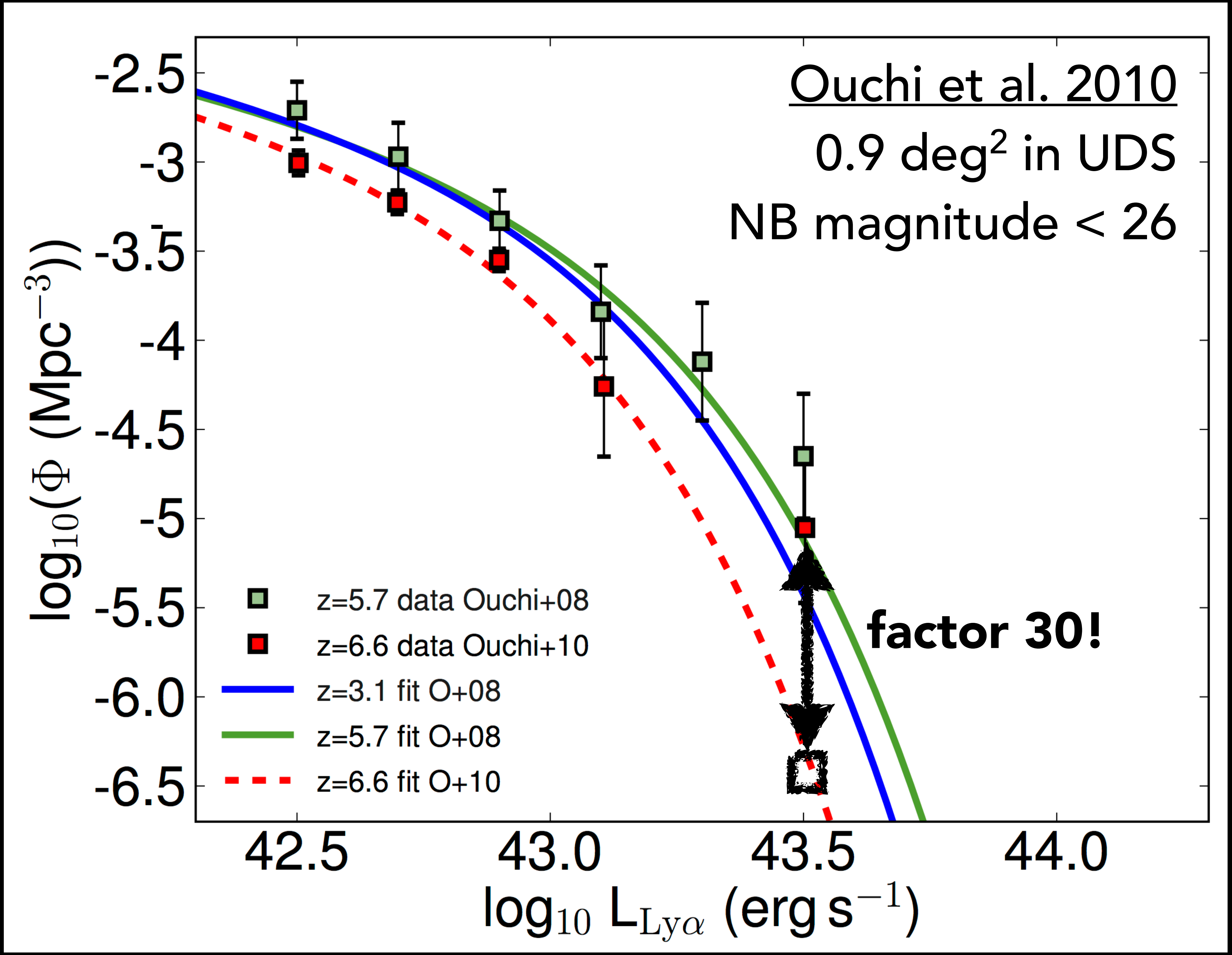
LYA AT Z=6.6

Evolution at all Luminosities (?)



LYA AT Z=6.6

Surveys limited by cosmic variance (<1deg^2)



OUR SURVEY:
5 DEG^2 IN UDS, COSMOS AND SA22

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

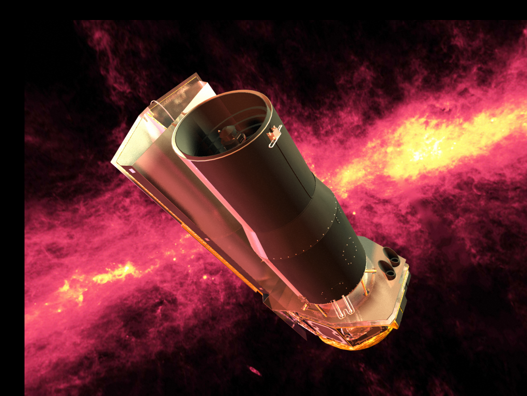
Surveys:

SDXF, UKIDSS-UDS, SpUDS, UDSz

COSMOS, UltraVISTA, S-COSMOS, zCOSMOS

CFHTLS, UKIDSS-DXS

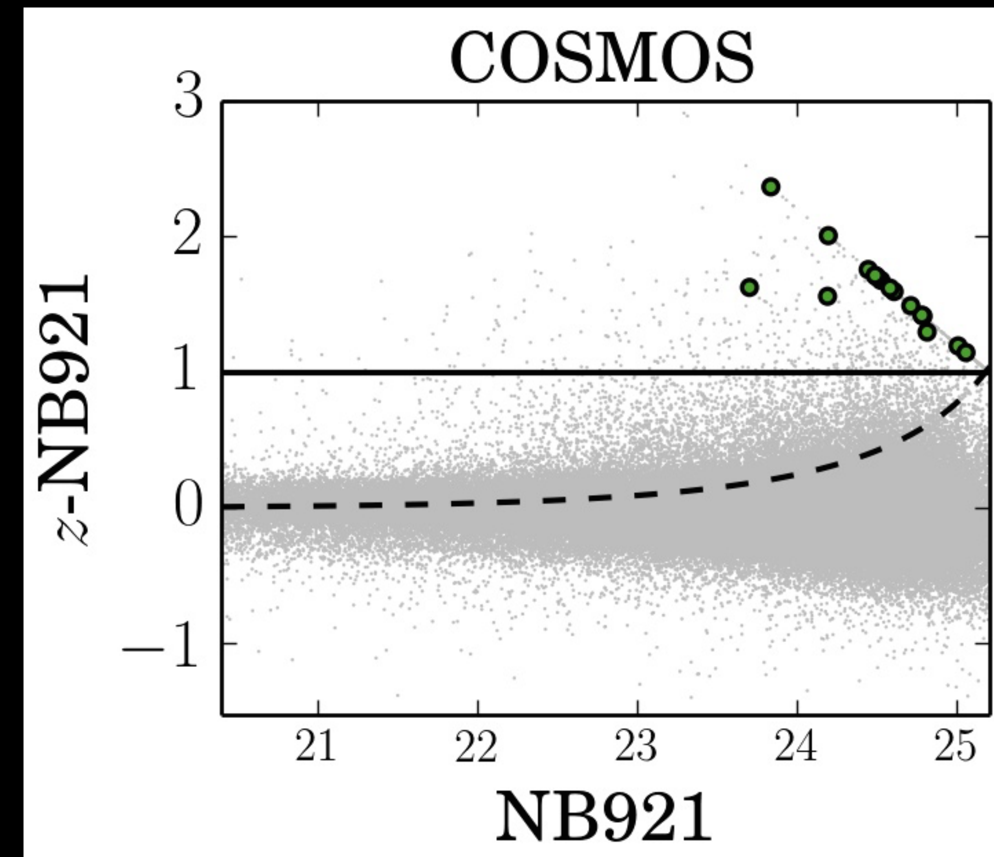


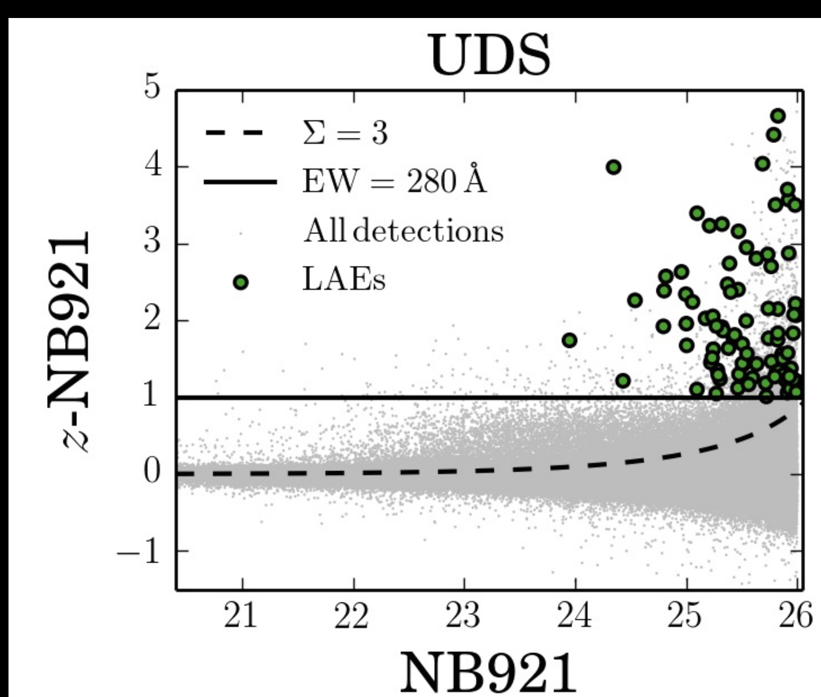



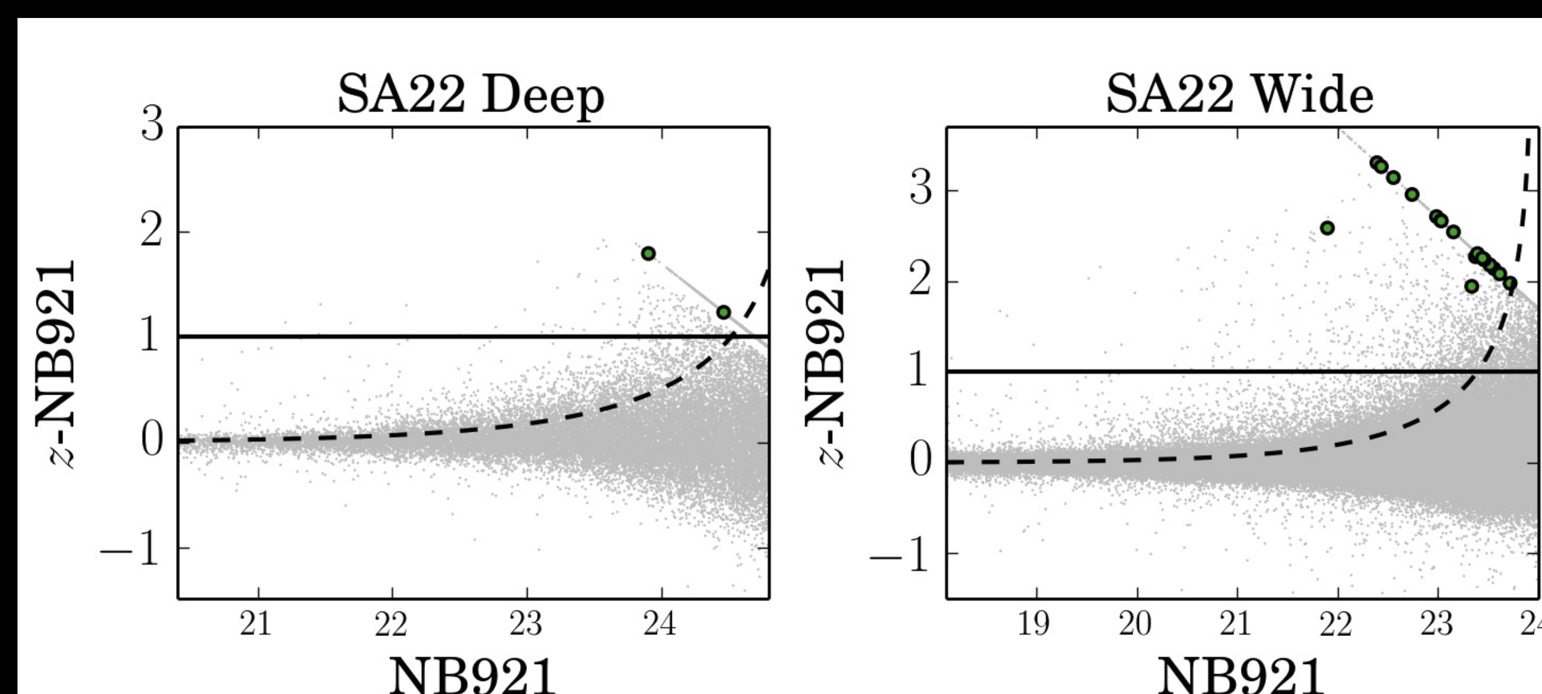

Matthee et al. 2015 (arXiv:1502.07355)

SELECTION CRITERIA FOR Z=6.6 LAE

- EW_{obs} > 300 Å
- Excess significance > 3
- ugri / BVRi > 3 sigma (Lyman break)
- J-K < 0.5 (blue restframe UV)







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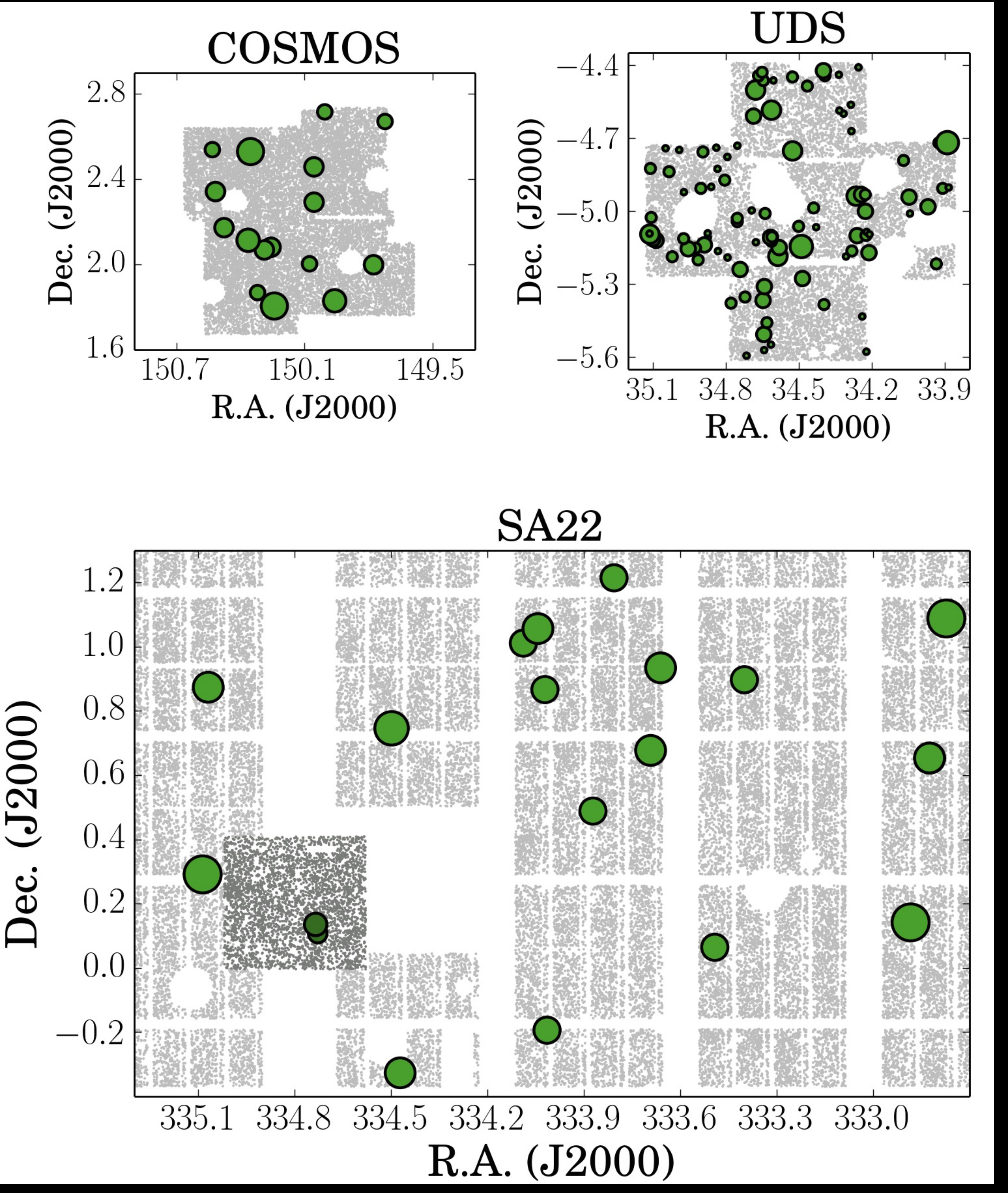
Results:

99 LAEs in UDS

15 LAEs in COSMOS

2 LAEs in SA22-Deep

18 LAEs in SA22-Wide



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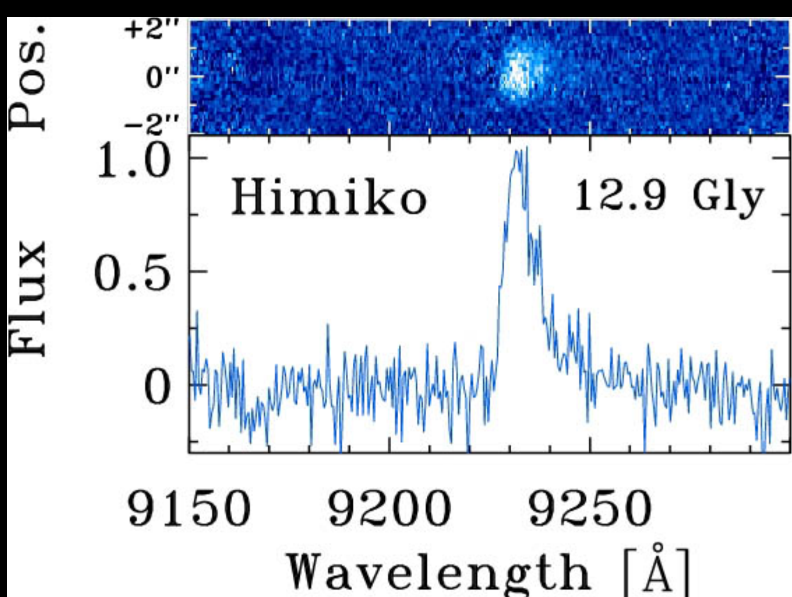
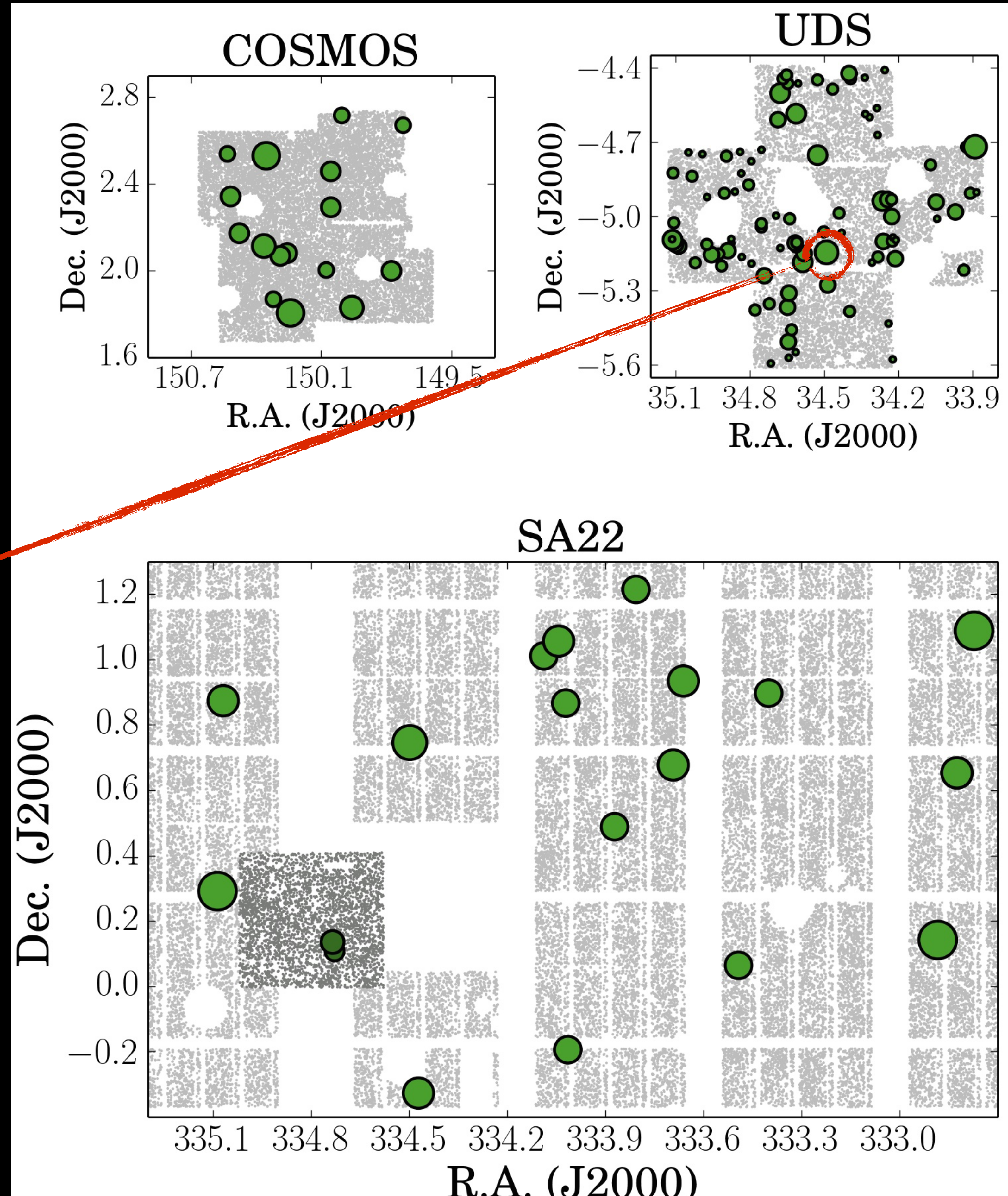
“Himiko”



Ouchi et al. 2009, 2013



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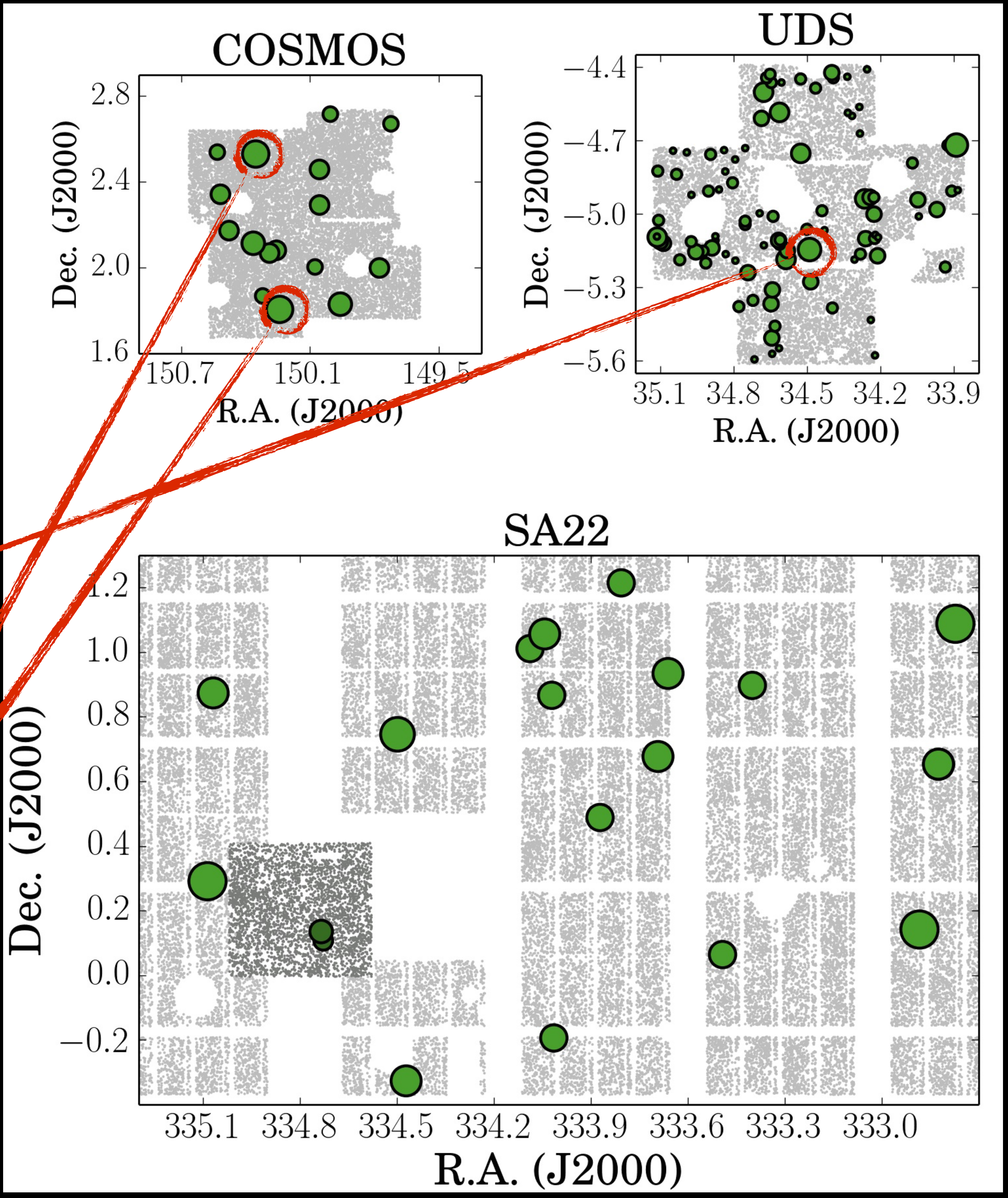
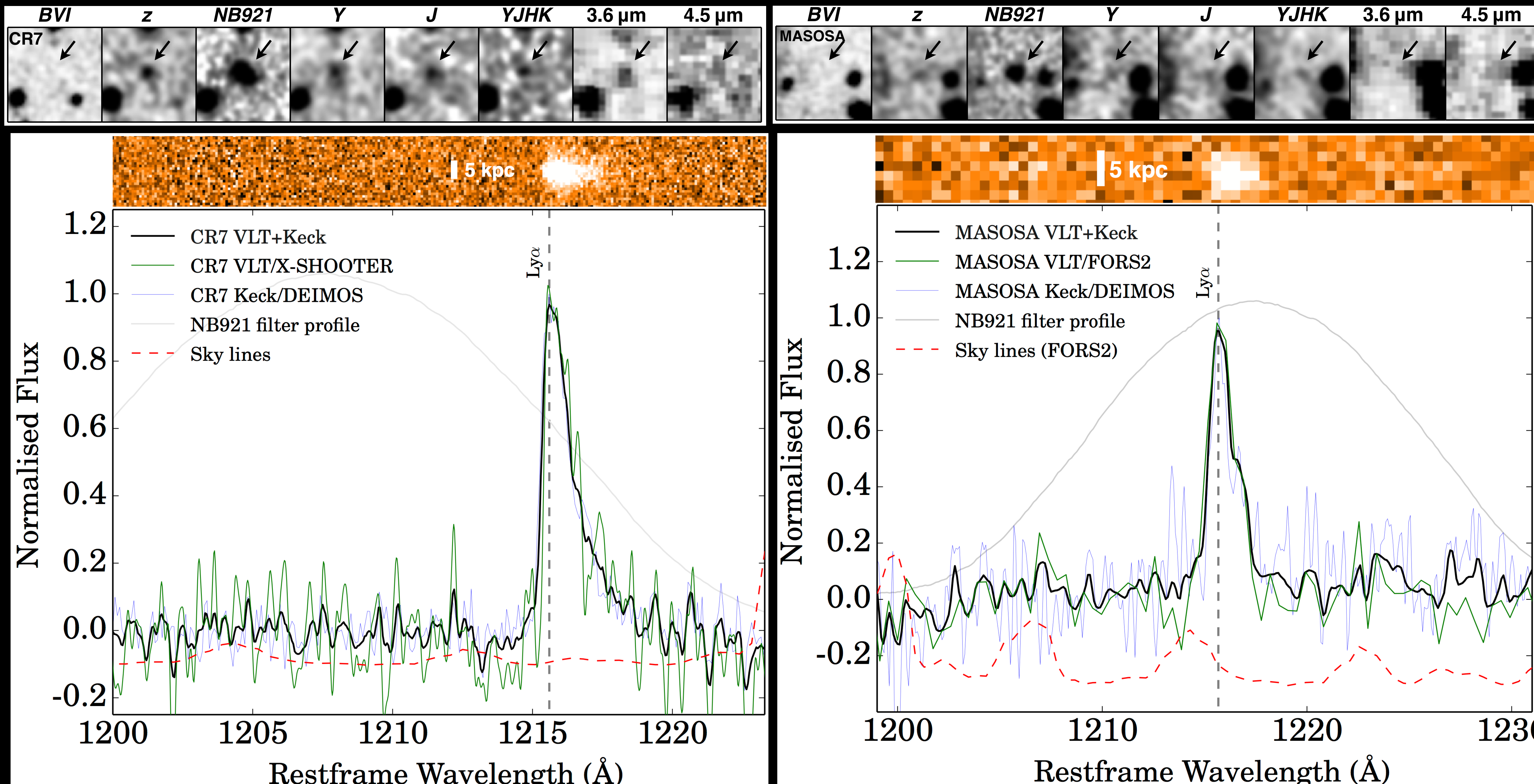
Even brighter!



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



VLT/X-Shooter + Keck/DEIMOS (~3.8 hours)

VLT/FORS2 + Keck/DEIMOS (~2.4 hours)

Sobral et al. (on the arXiv soon) Matthee et al. 2015 (arXiv:1502.07355)

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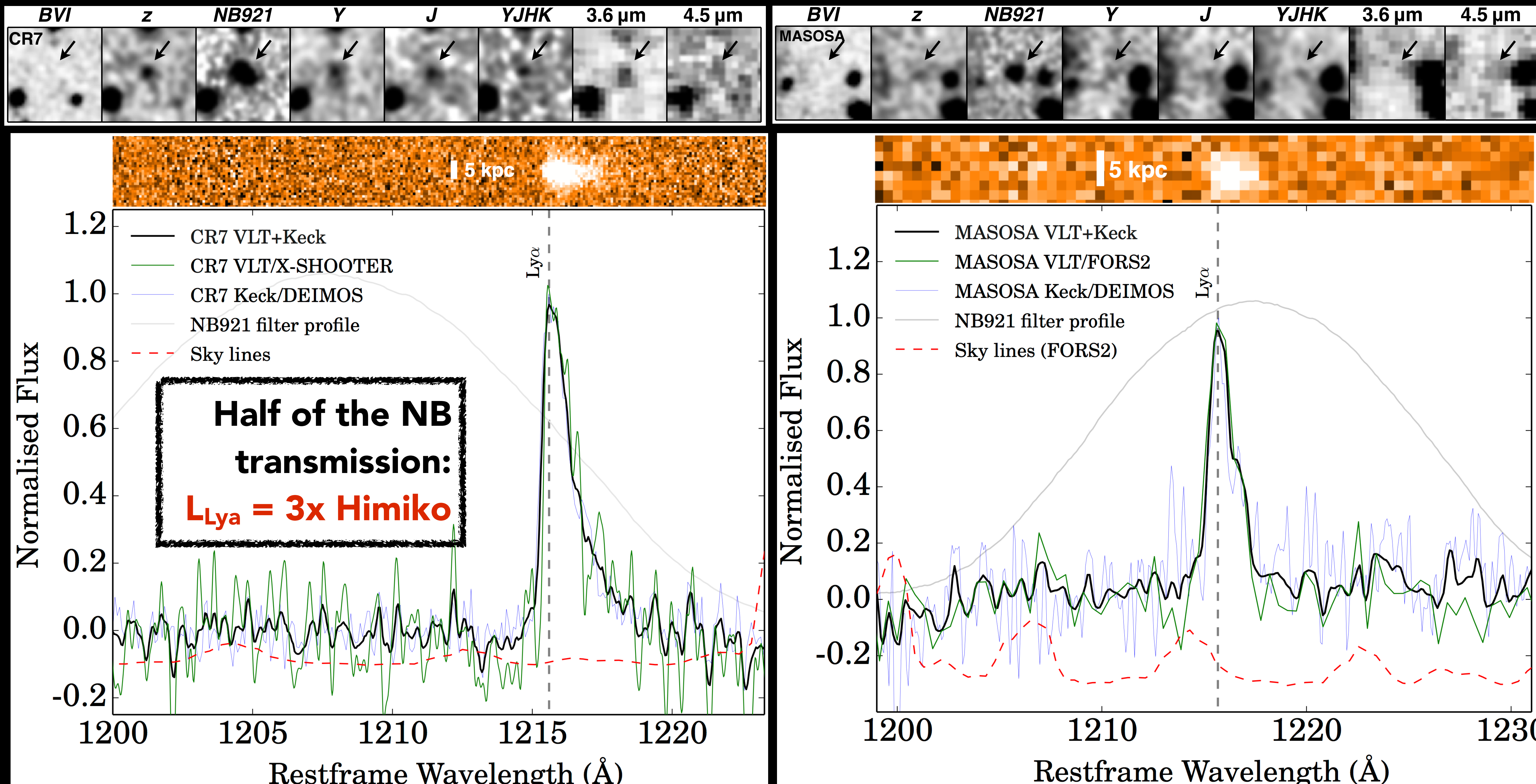

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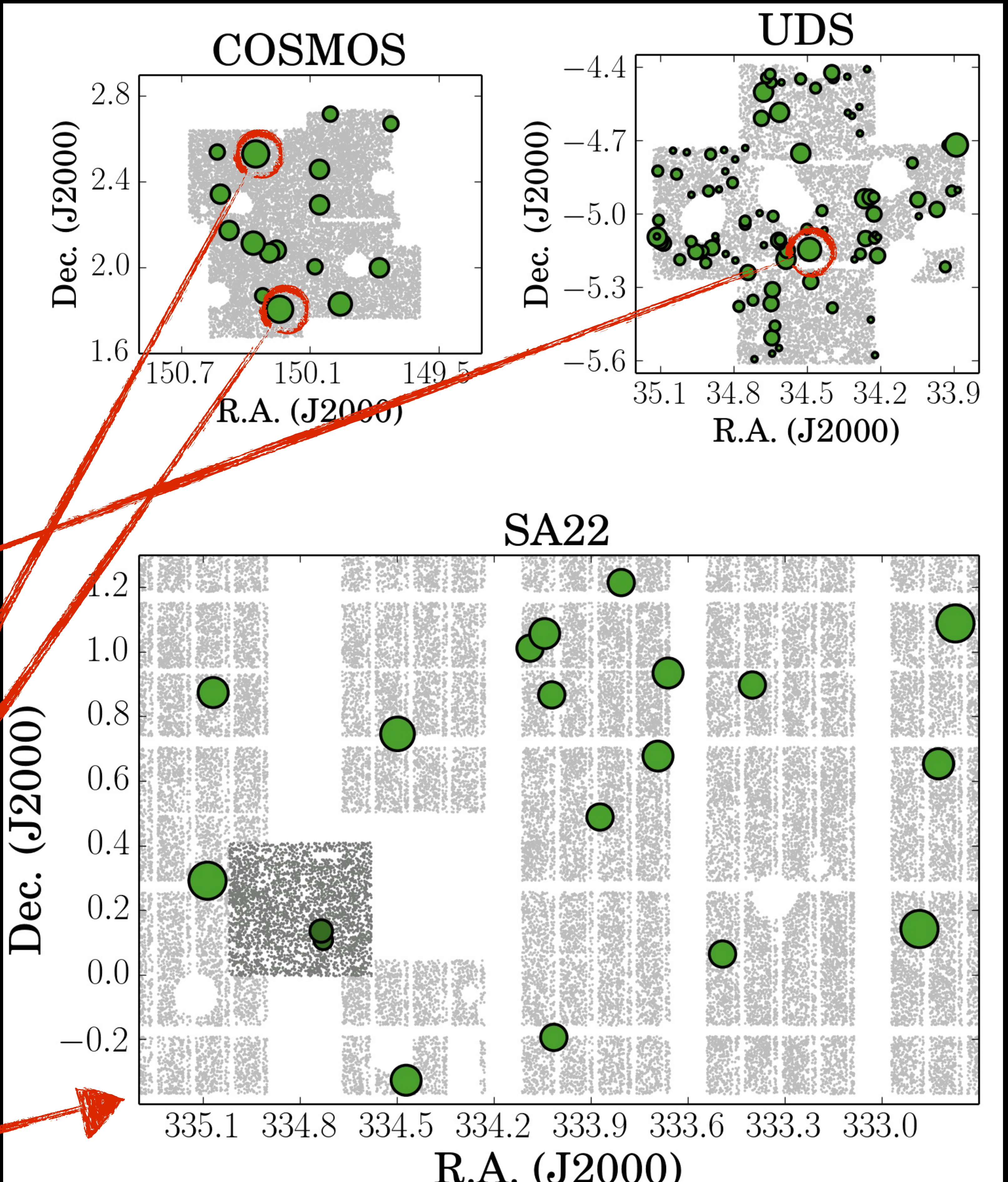
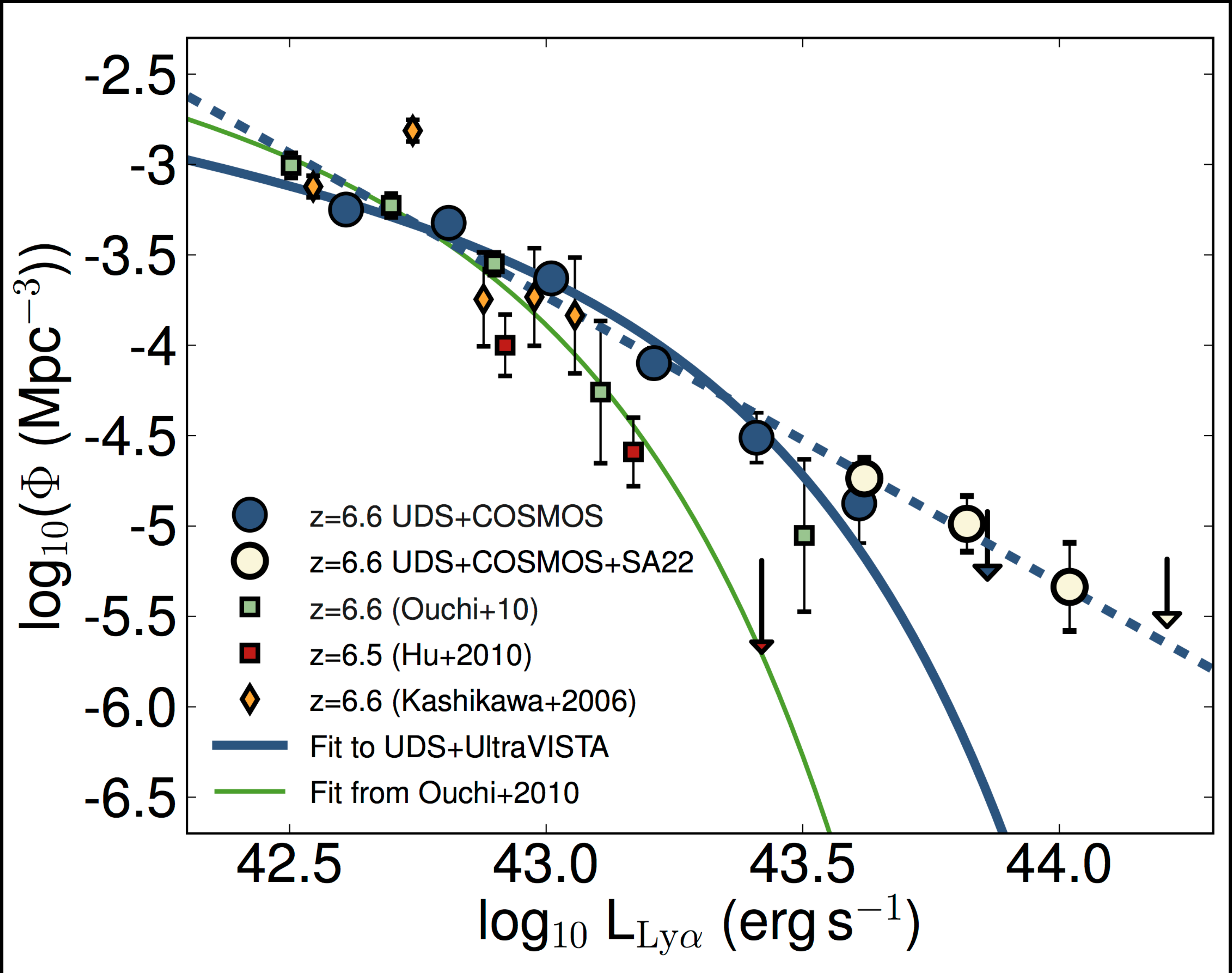


"Himiko"

Even brighter!

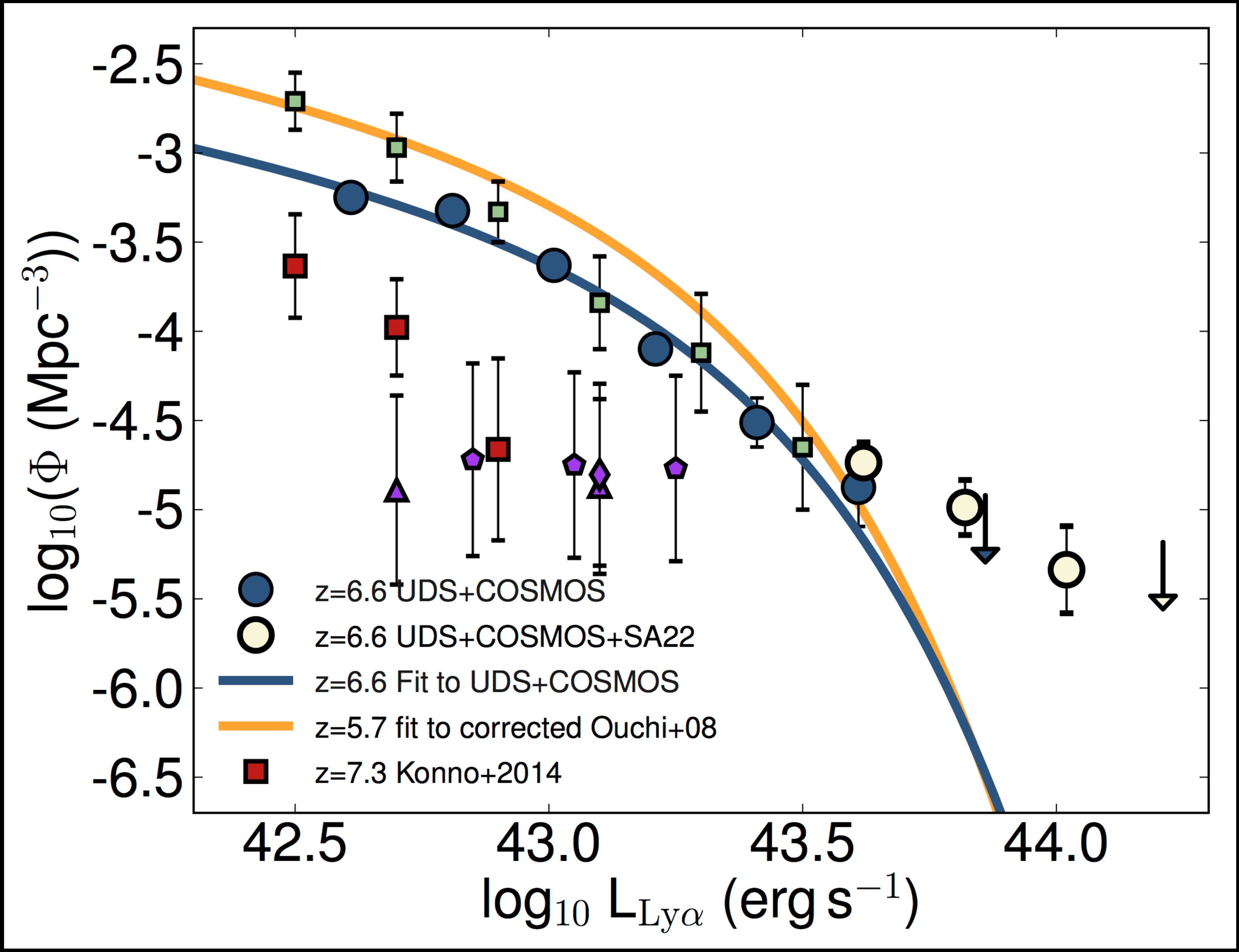
Confirms number density

LAE Z=6.6 LUMINOSITY FUNCTION



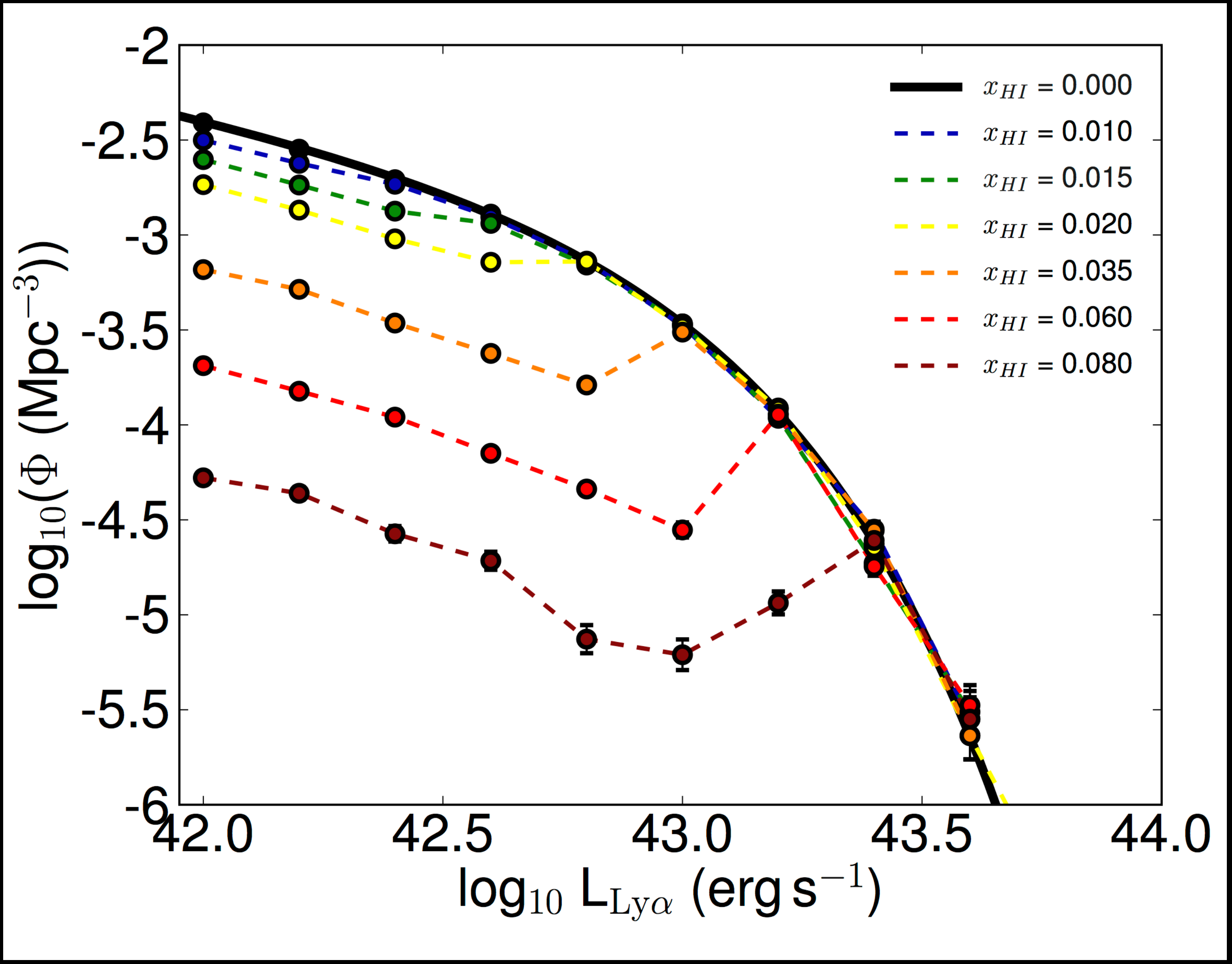
Matthee et al. 2015 (arXiv:1502.07355)

EVOLUTION FROM Z=6.6 TO Z=5.7



Matthee et al. 2015 (arXiv:1502.07355)

TOY MODEL FOR LF EVOLUTION DUE TO RE-IONISATION

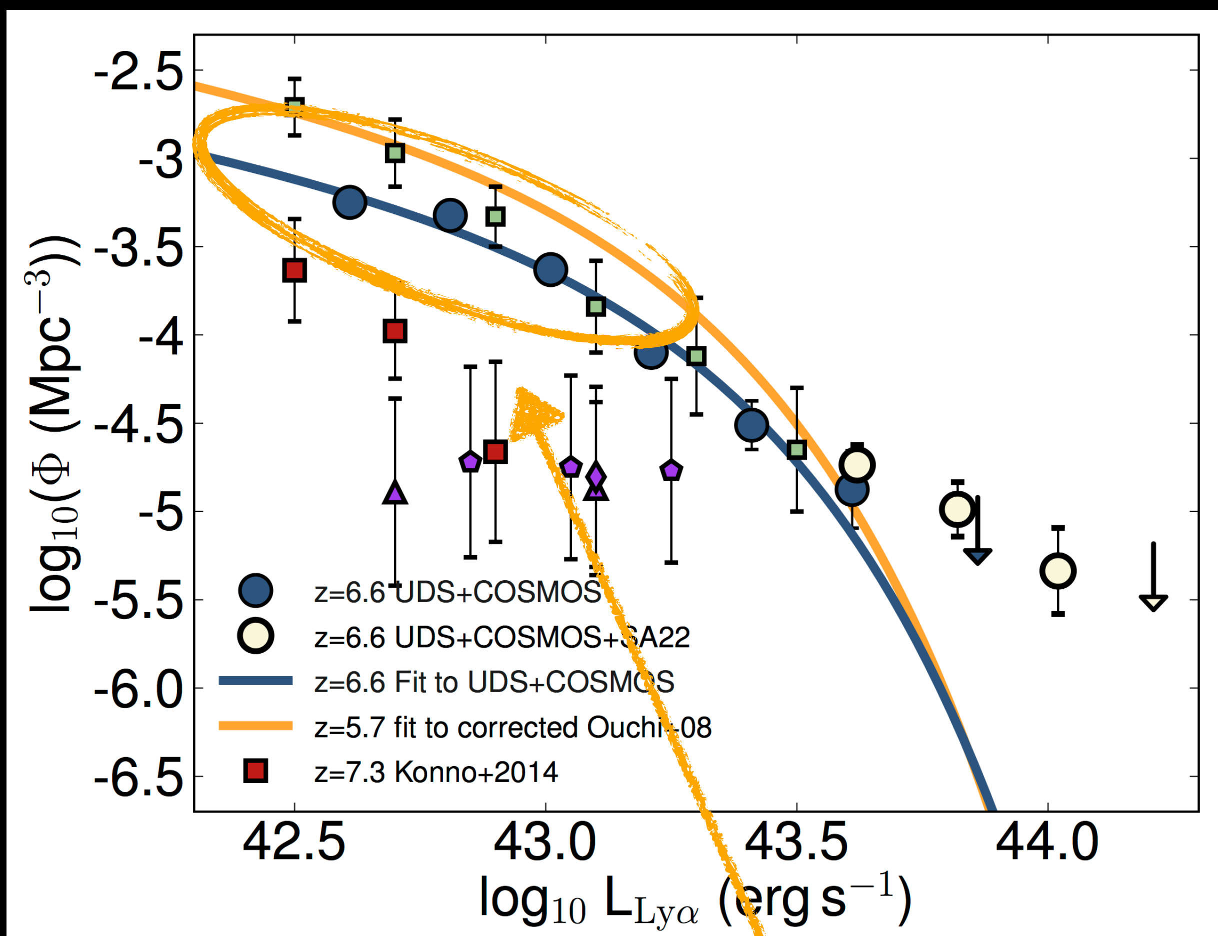


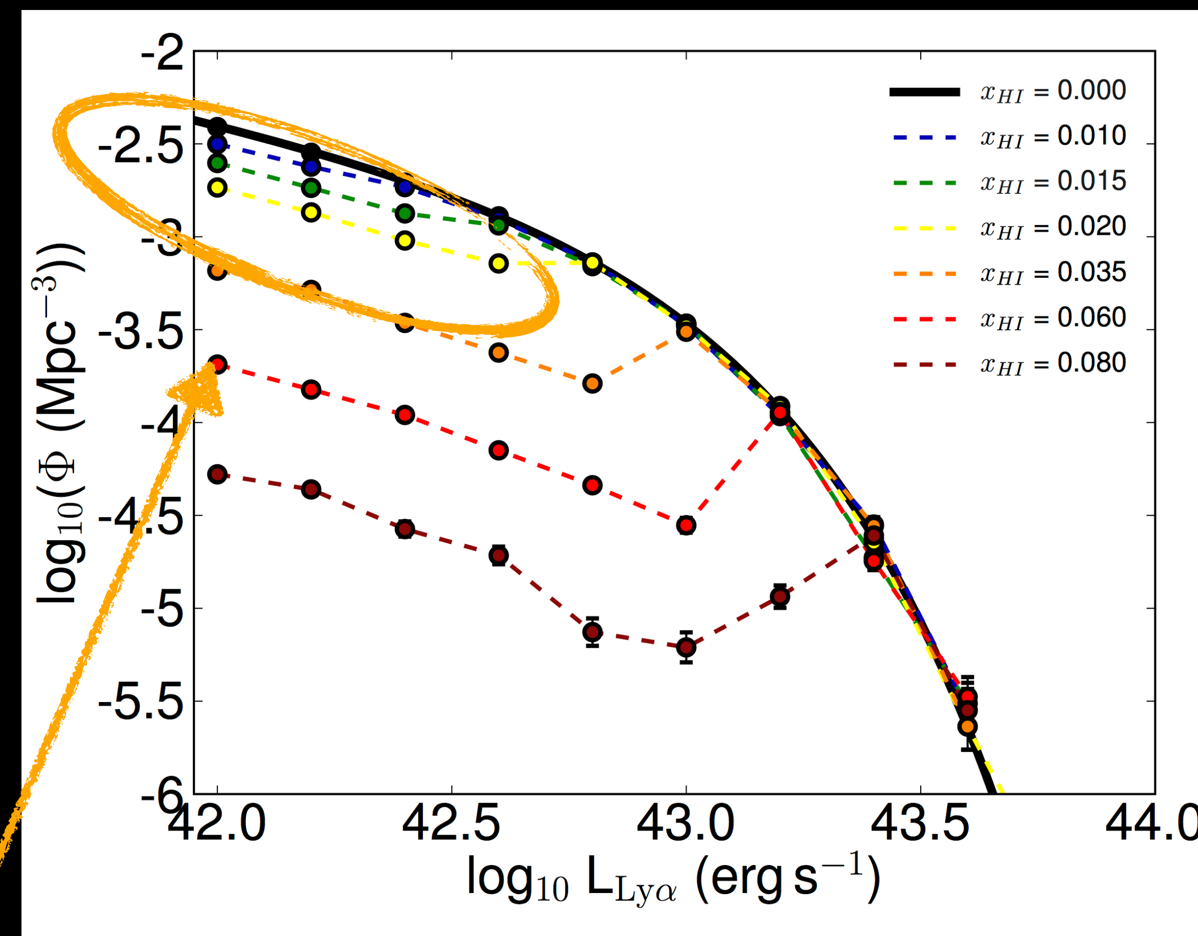
- LAE only observed in large enough ionised region
- Luminous LAEs easier to observe

Matthee et al. 2015 (arXiv:1502.07355)

EVOLUTION FROM Z=6.6 TO Z=5.7

z=5.7 to z=6.6 evolution



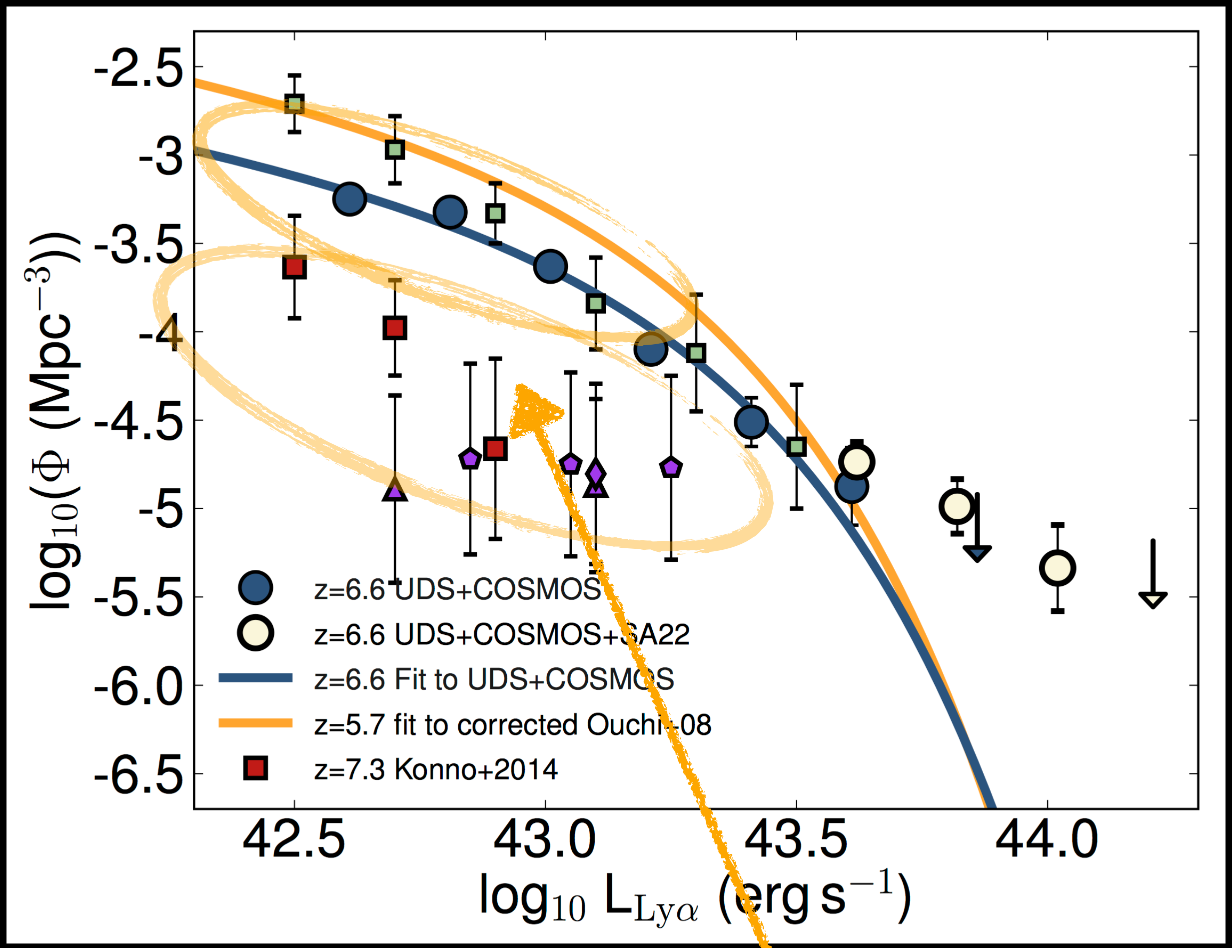


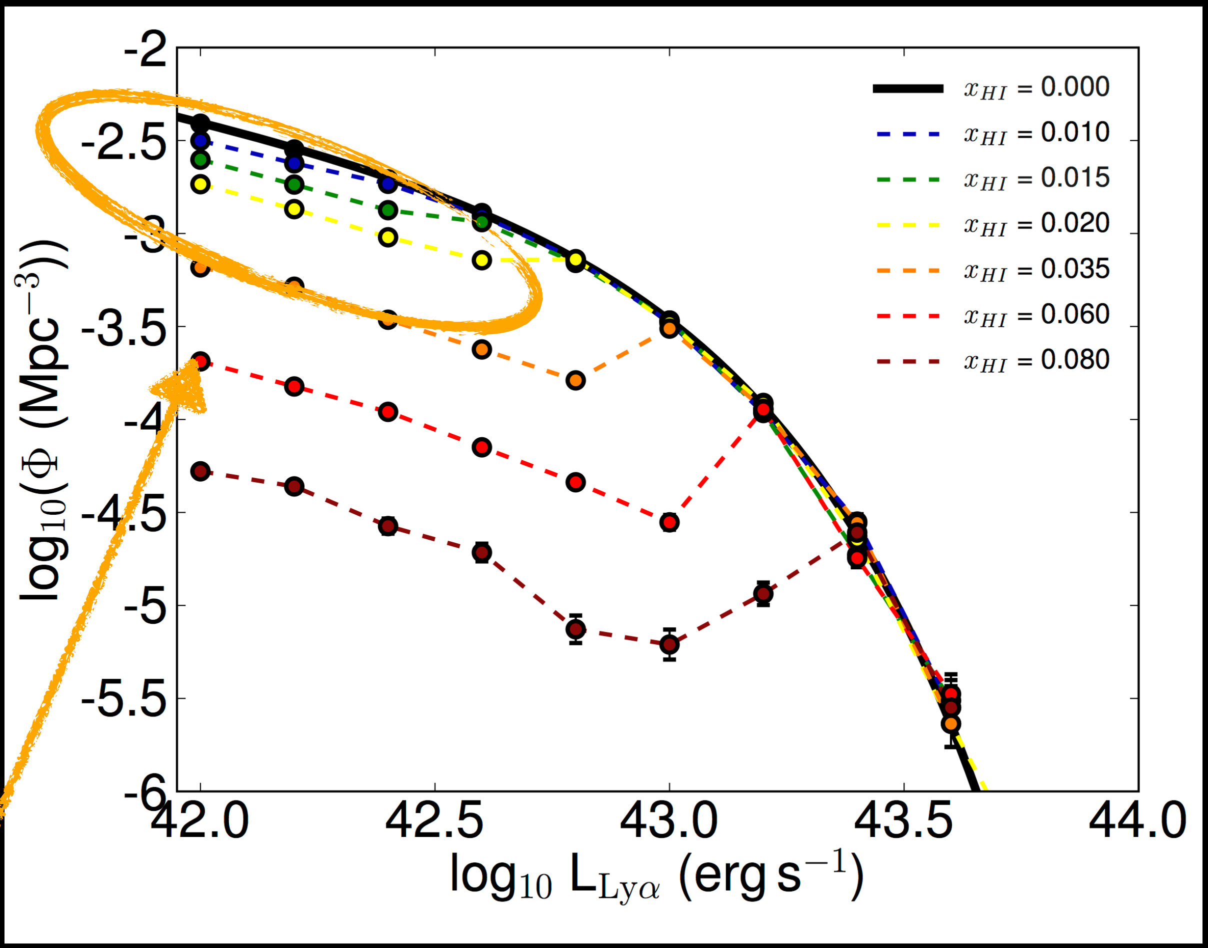
Bulk of the evolution happens at the faint end!

Matthee et al. 2015 (arXiv:1502.07355)

EVOLUTION FROM Z=6.6 TO Z=5.7

z=6.6 to z=7.3 evolution





Bulk of the evolution happens at the faint end!

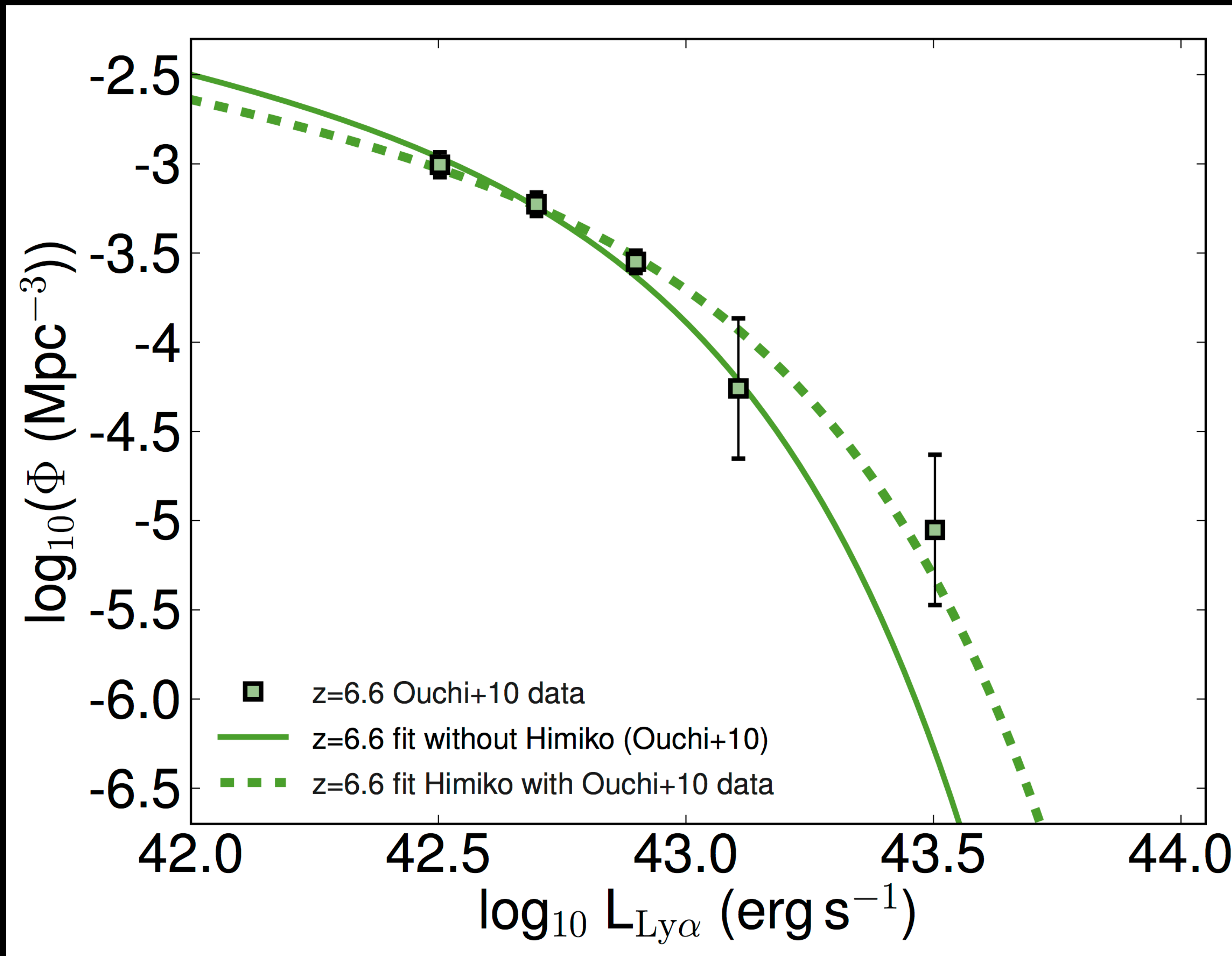
Matthee et al. 2015 (arXiv:1502.07355)

CONCLUSIONS

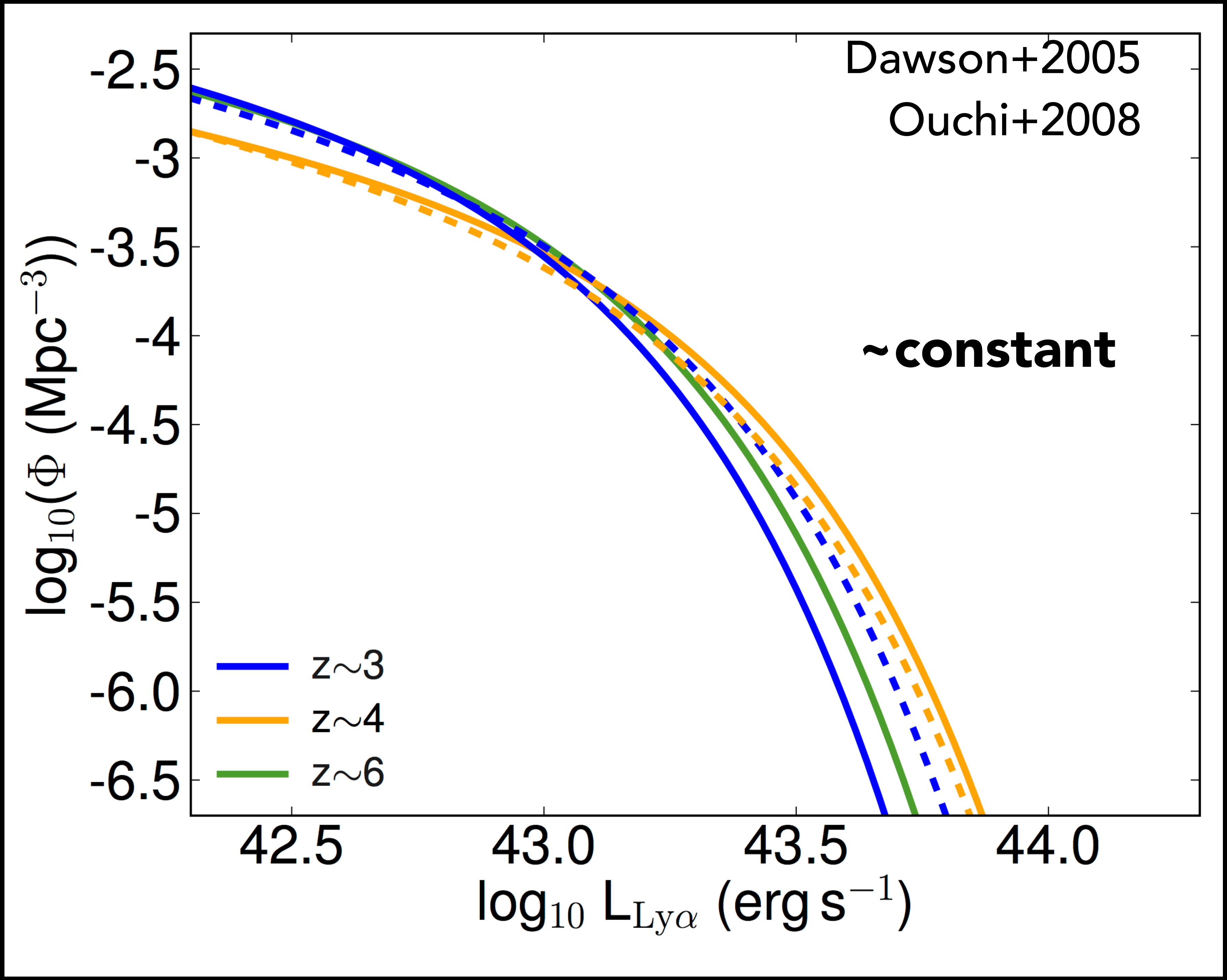
- We have obtained a new z=6.6 Lyα LF using data in UDS, COSMOS and SA22
- We spectroscopically confirm the two brightest LAE at z=6.6 so far, meaning that sources with luminosity similar to *Himiko* are not as rare as thought, and have number densities of ~ 1.5 per 10^5 Mpc^3
- There is differential evolution of the LF from z=6.6 to z=5.7, which we argue is an effect of re-ionisation not being completed

Matthee et al. 2015 (arXiv:1502.07355)

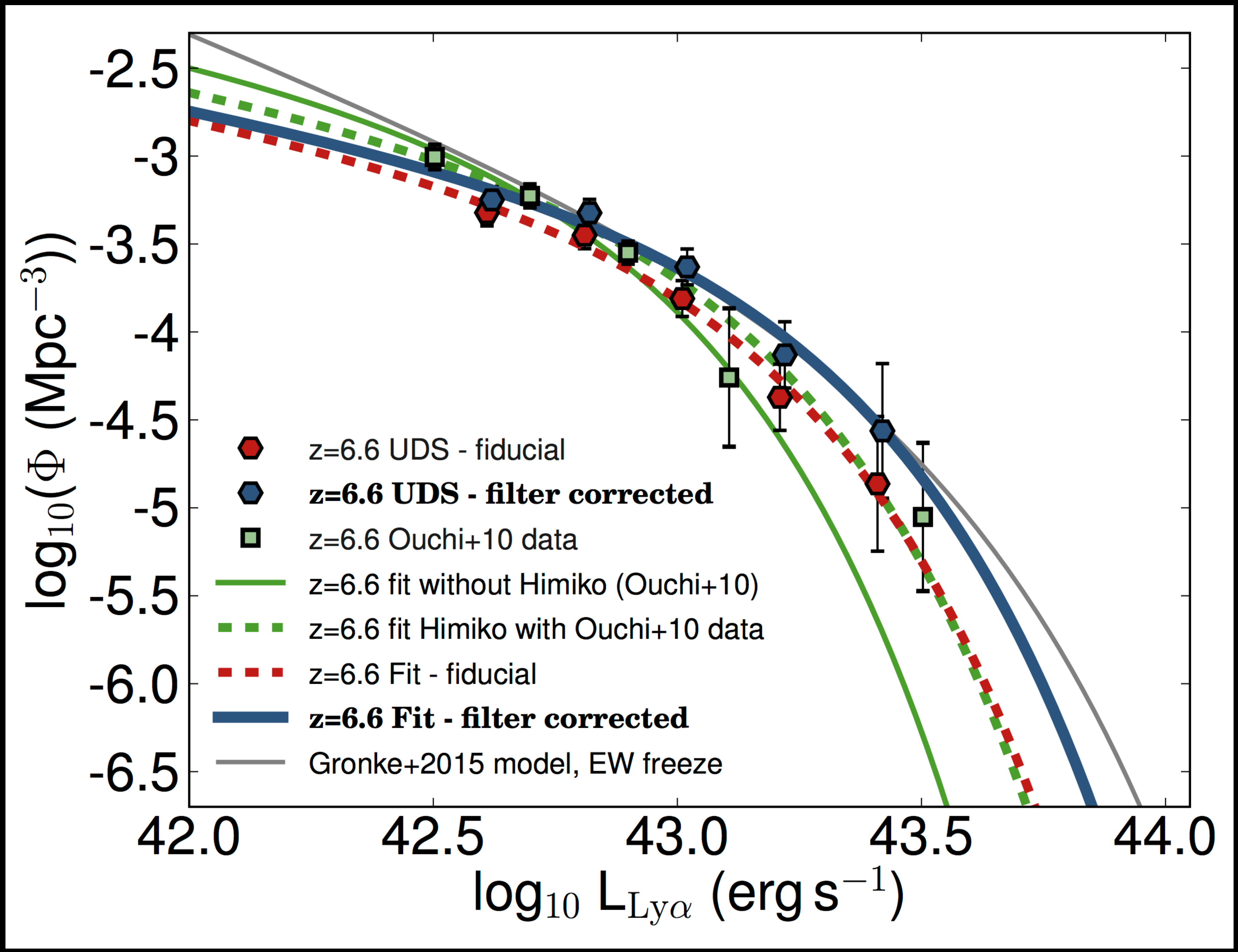
Ouchi+2010 data and fit - and our fit incl. Himiko



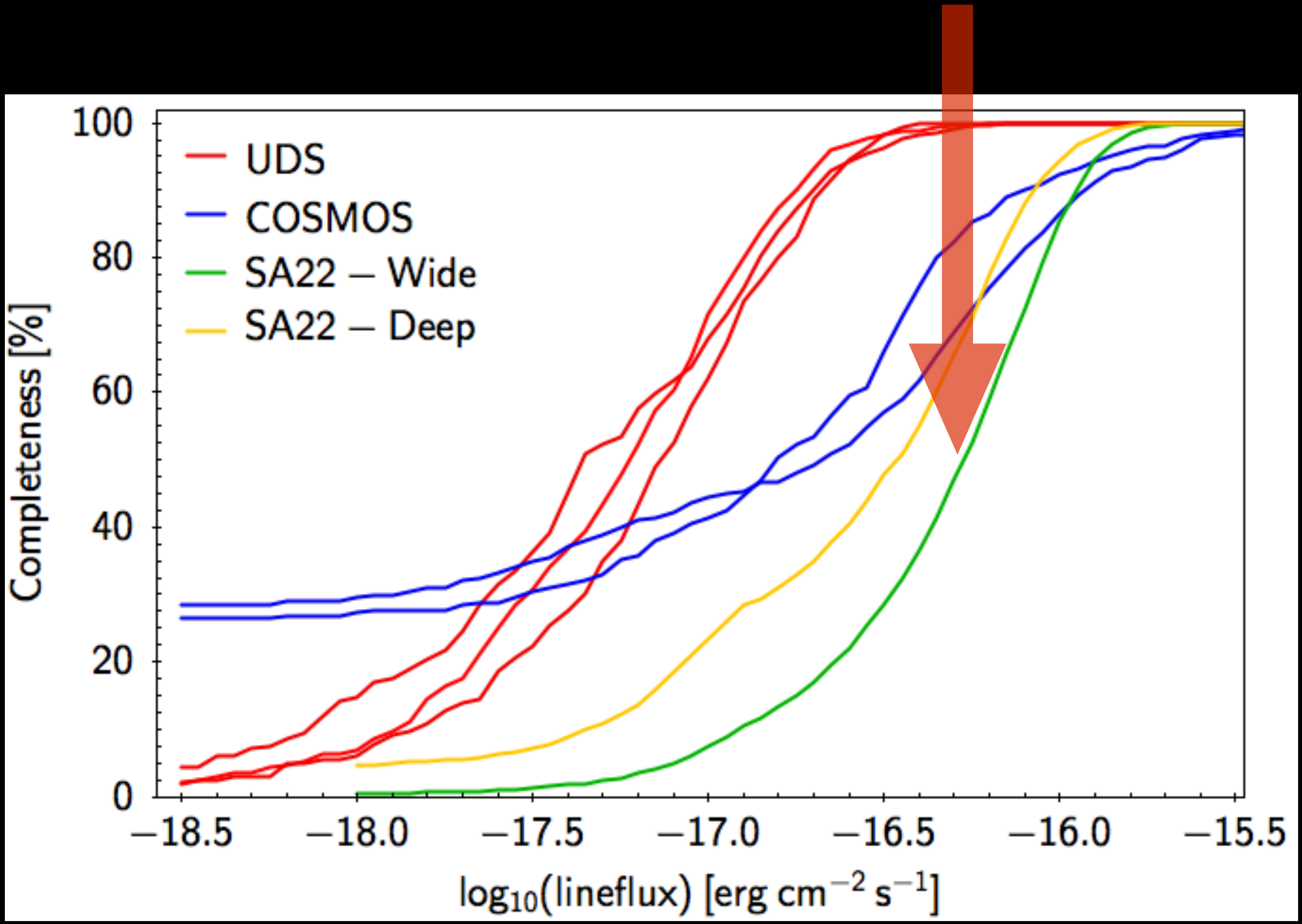
EVOLUTION OF THE LYA LF Z=3-6



We reproduce Ouchi+2010 in UDS



COMPLETENESS



TOY MODEL FOR 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

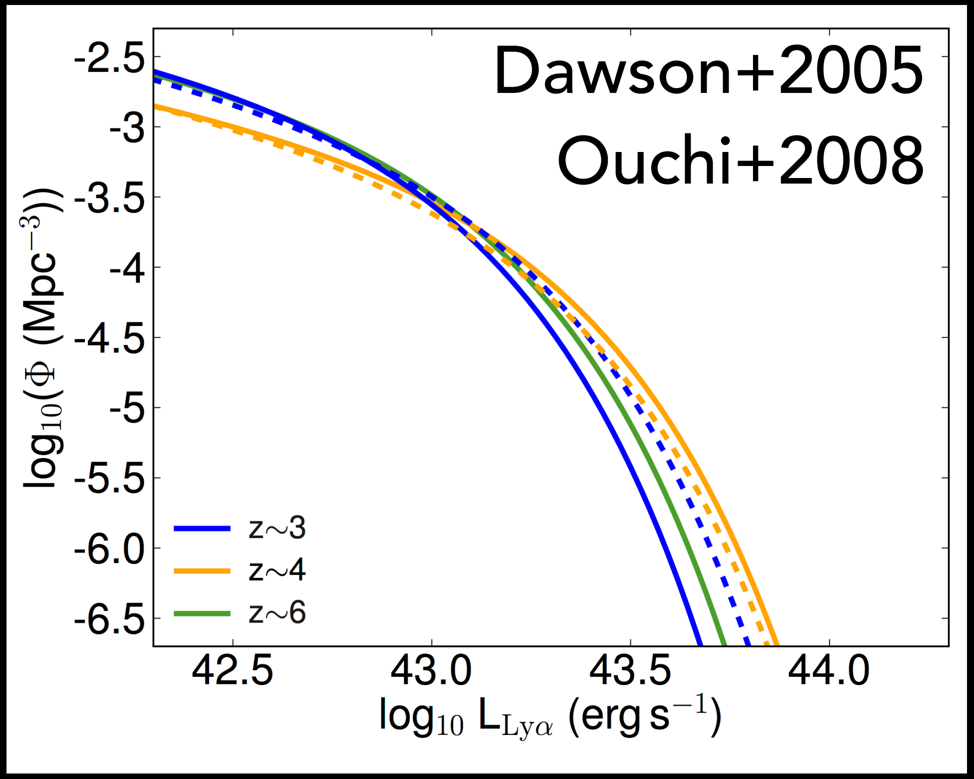
$$L(H\alpha) = 8.6 f_{esc,Ly\alpha} L(Ly\alpha) \;\; \mathrm{erg\ s^{-1}}$$

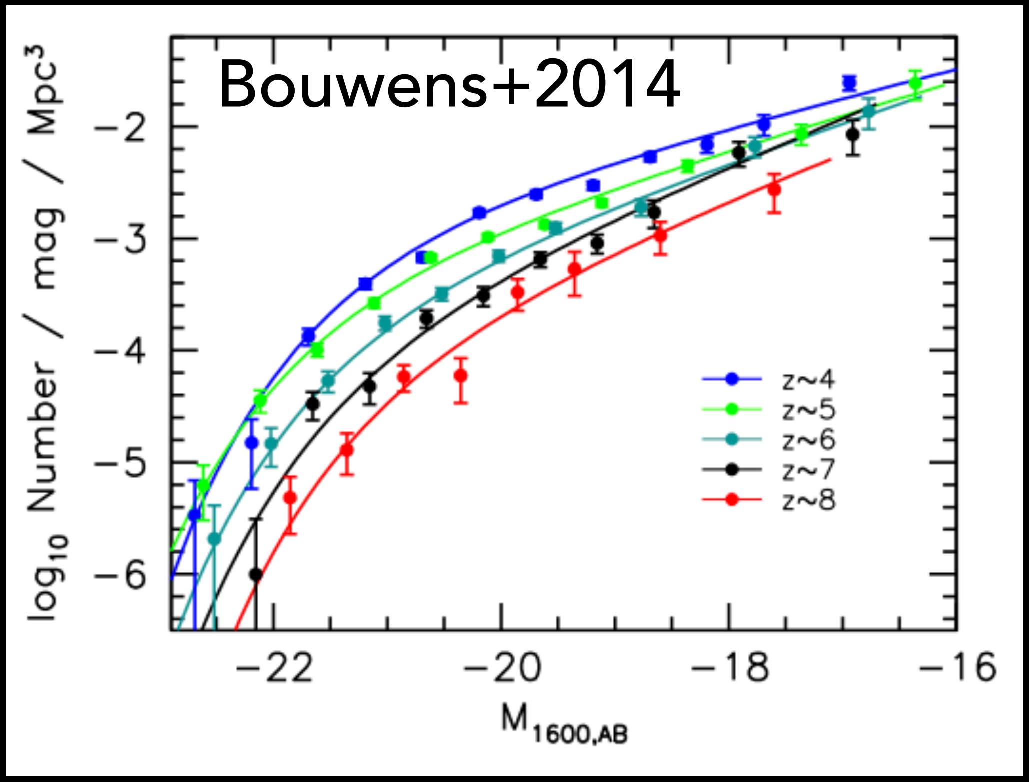
$$N_{\gamma,em} = \frac{L(H\alpha)}{1.37 \times 10^{-12}} \;\; \mathrm{s^{-1}}$$

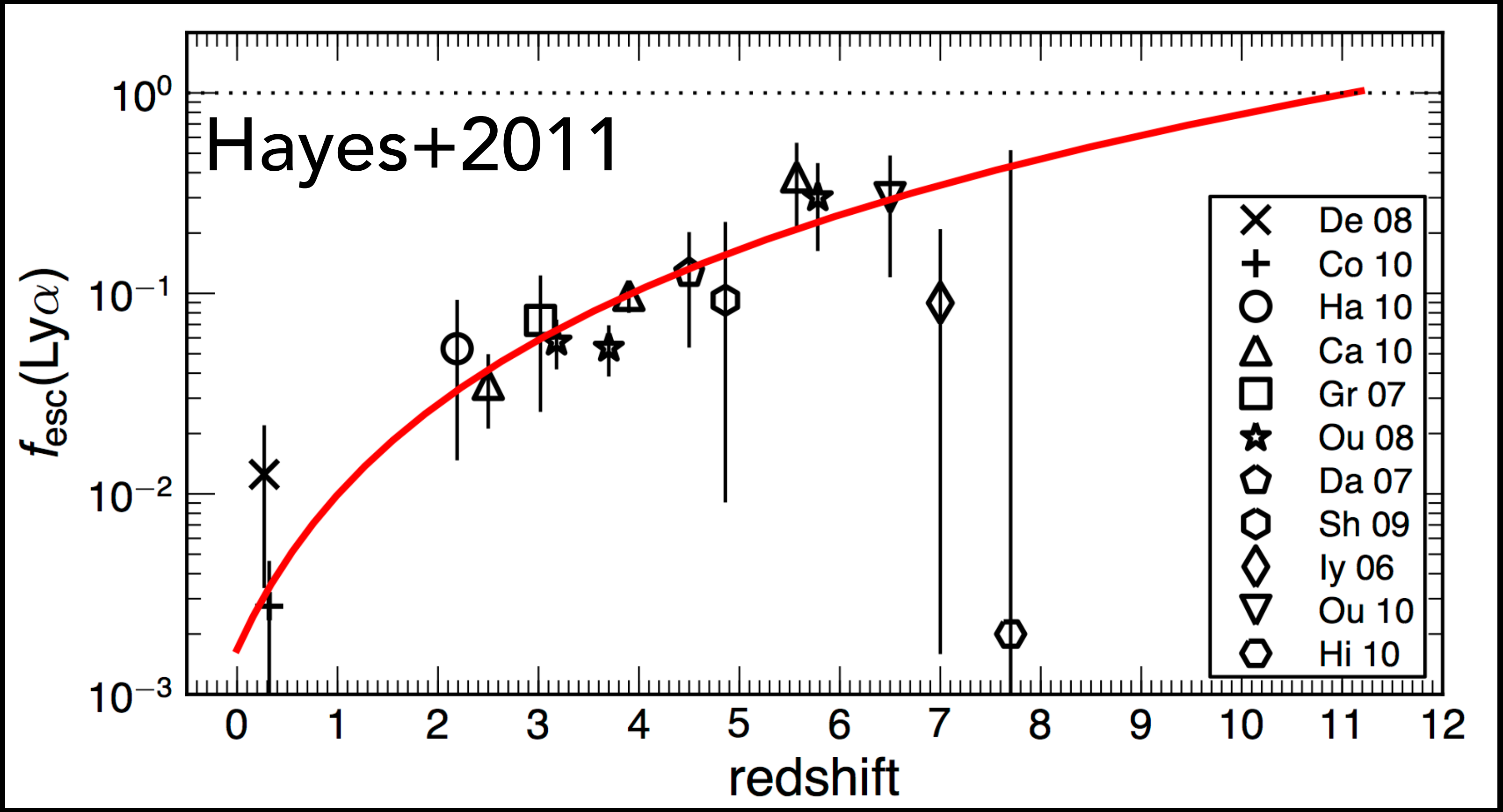
$$R_S = 4.3\, x_{\mathrm{IGM}}^{-1/3} \left(\frac{f_{esc,ion} N_{\gamma,em}}{1.3 \times 10^{57}\mathrm{s}^{-1}}\right)^{1/3} \left(\frac{t}{2 \times 10^{7}\mathrm{yr}}\right)^{1/3} \;\mathrm{Mpc}$$

Matthee et al. 2015 (arXiv:1502.07355)

EVOLUTION LAE & LBG





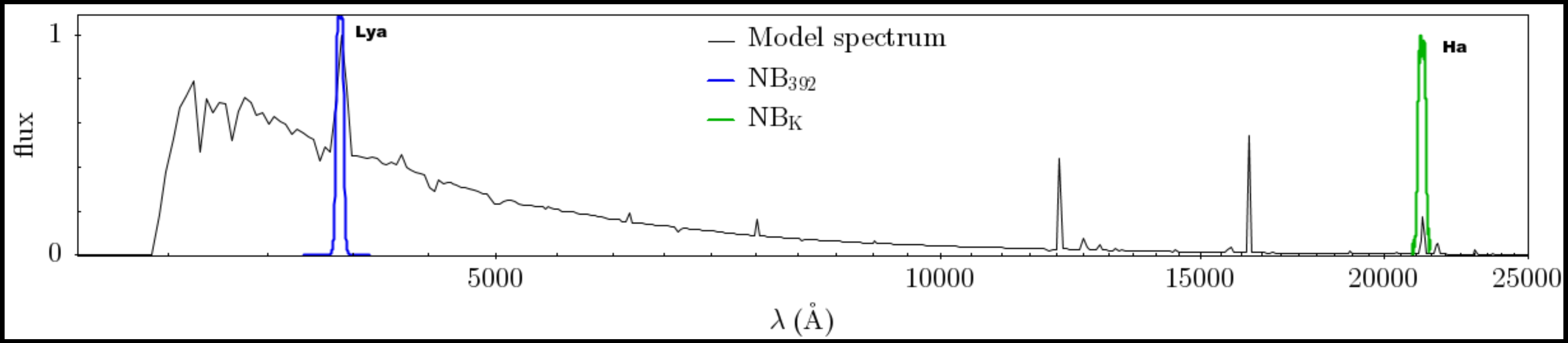


Lya escape fraction

~40% of the data (rest is coming this December-January)

Lya escape fraction: 4+-4% consistent with Hayes+2011

(**for LAEs: 30+-3%** consistent with Wardlow+2014, based on far IR)

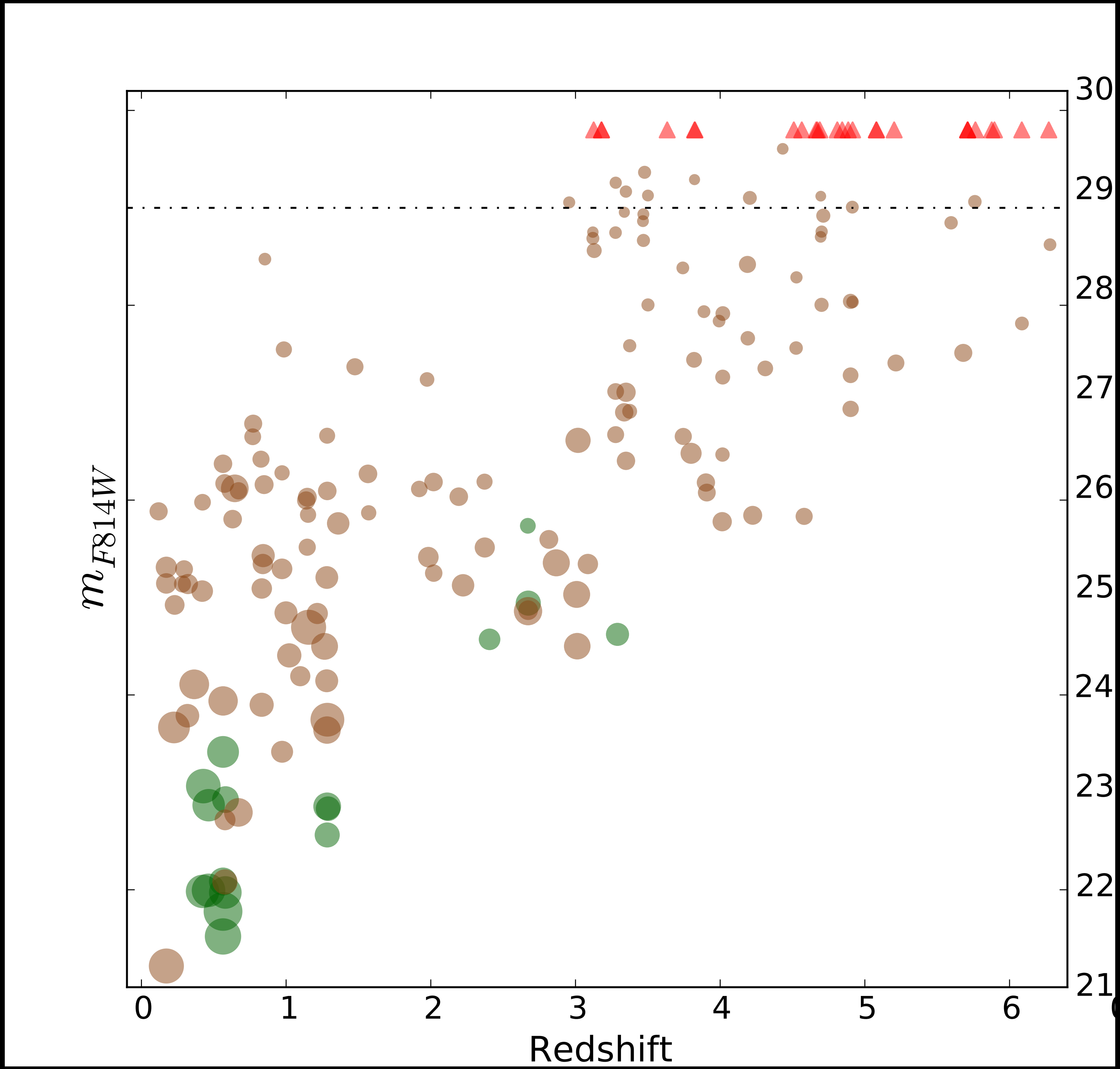


Narrow-band technique -> double NB technique

1. sample of ~500 Ha emitters at z=2.23
2. place the NB392 filter at the INT
3. observe Lya emission line for these galaxies
4. measure the Lya flux -> escape fraction

- JM identifies sources at November 4 and 5, 2014
- DS is in Hawaii and tries to convince Keck staff for observations - fail
- December: JM, DS & HR apply for DDT time VLT/FORS2 - success
- Christmas: Benham goes to Hawaii, confirms brightest source with 15 minutes raw exposure with Keck/DEIMOS, bad weather for the other- success/fail
- January 2015: DS & JM convince ESO to observe this target with X-Shooter - success
- January 2015: ESO staff at VLT confirms second source with a misaligned exposure. Moon prevents X-Shooter observations - success/fail
- February 2015: X-Shooter observations reveal ~ 2 sigma HeII
- March 2015: 8 hours of SINFONI DDT time granted by ESO with priority A

C R 7 … how special is it?



MUSE, HDF (Bacon, Brinchmann, et al. 2014)

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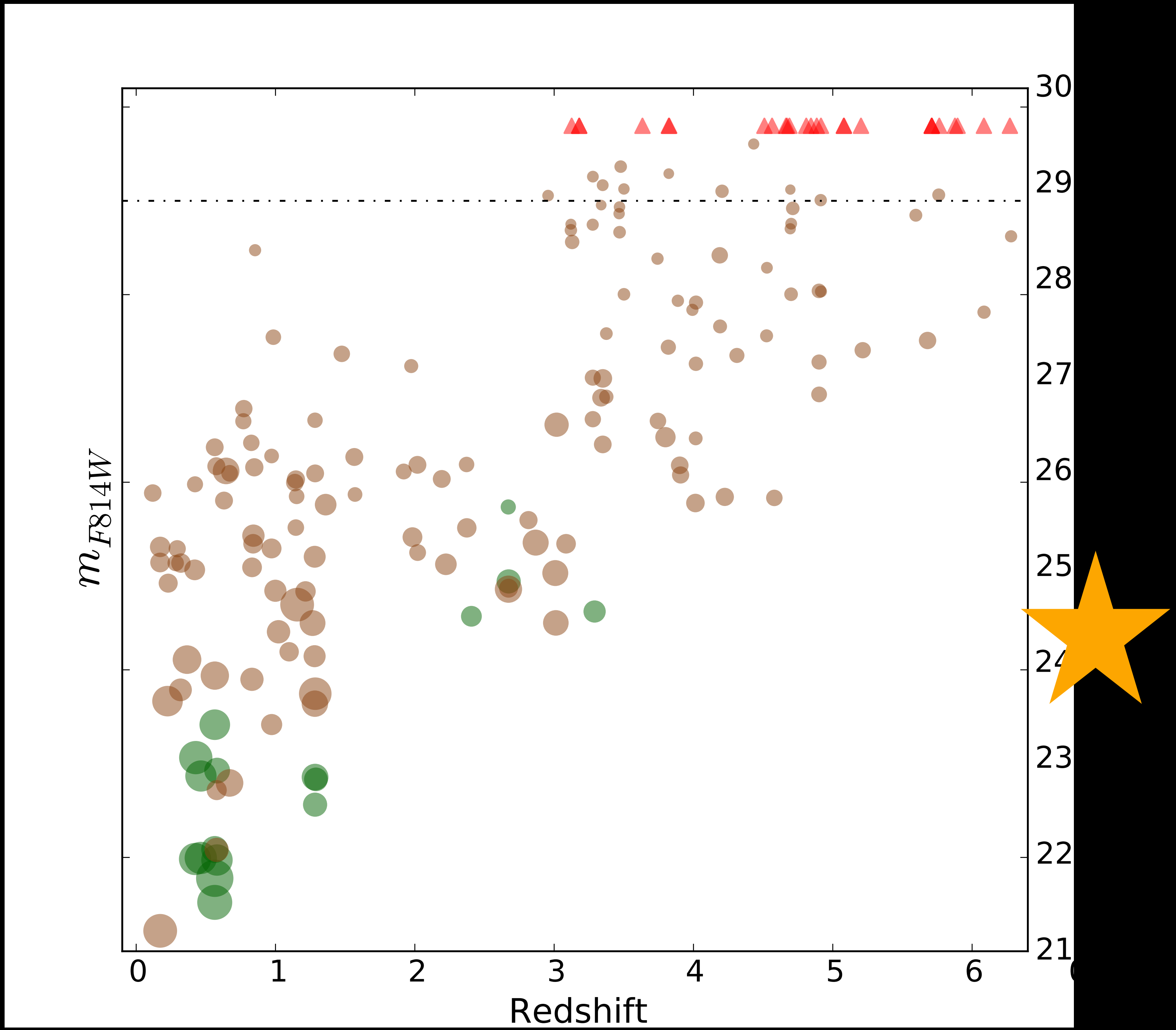
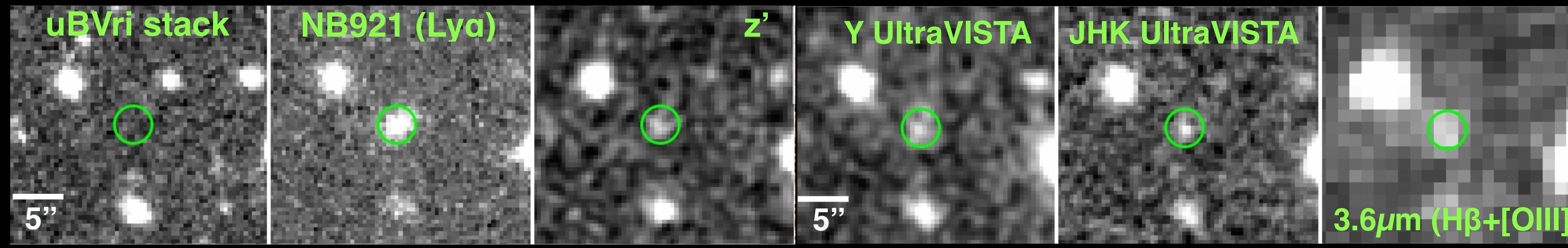


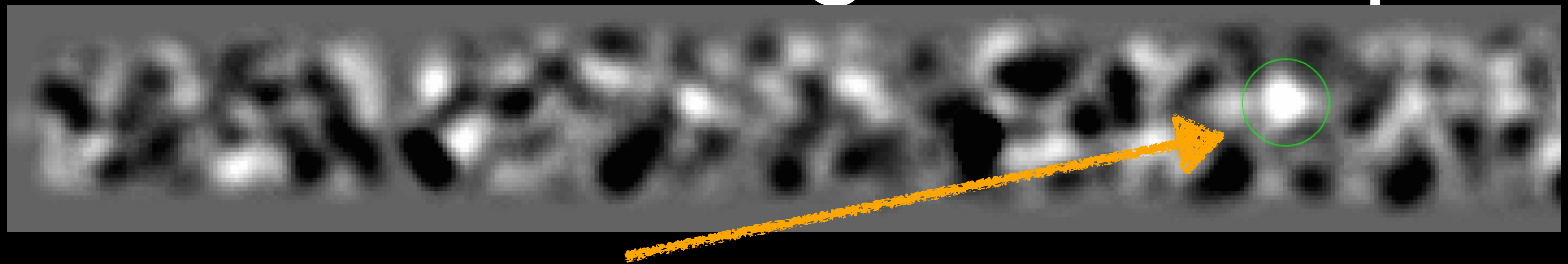
MUSE, HDF (Bacon, Brinchmann, et al. 2014)

Sobral et al. (in prep)

CR7...



- extended up to ~15 kpc
- detected in NIR: very blue UV slope (Bowler+2013)
- blue IRAC [3.6]-[4.5] colours: strong nebular emission lines
- FUV detected in Keck/DEIMOS spectra: ultra blue UV slope, indicating young age and low metallicity
- narrow Lya line, no X-ray detection, no broad lines: clearly a galaxy and not an AGN
- tentative detection of HeII1640Å: gun-smoke proof of PopIII stars (?)



To be continued…