Unveiling the active early galaxy assembly with emission-lines

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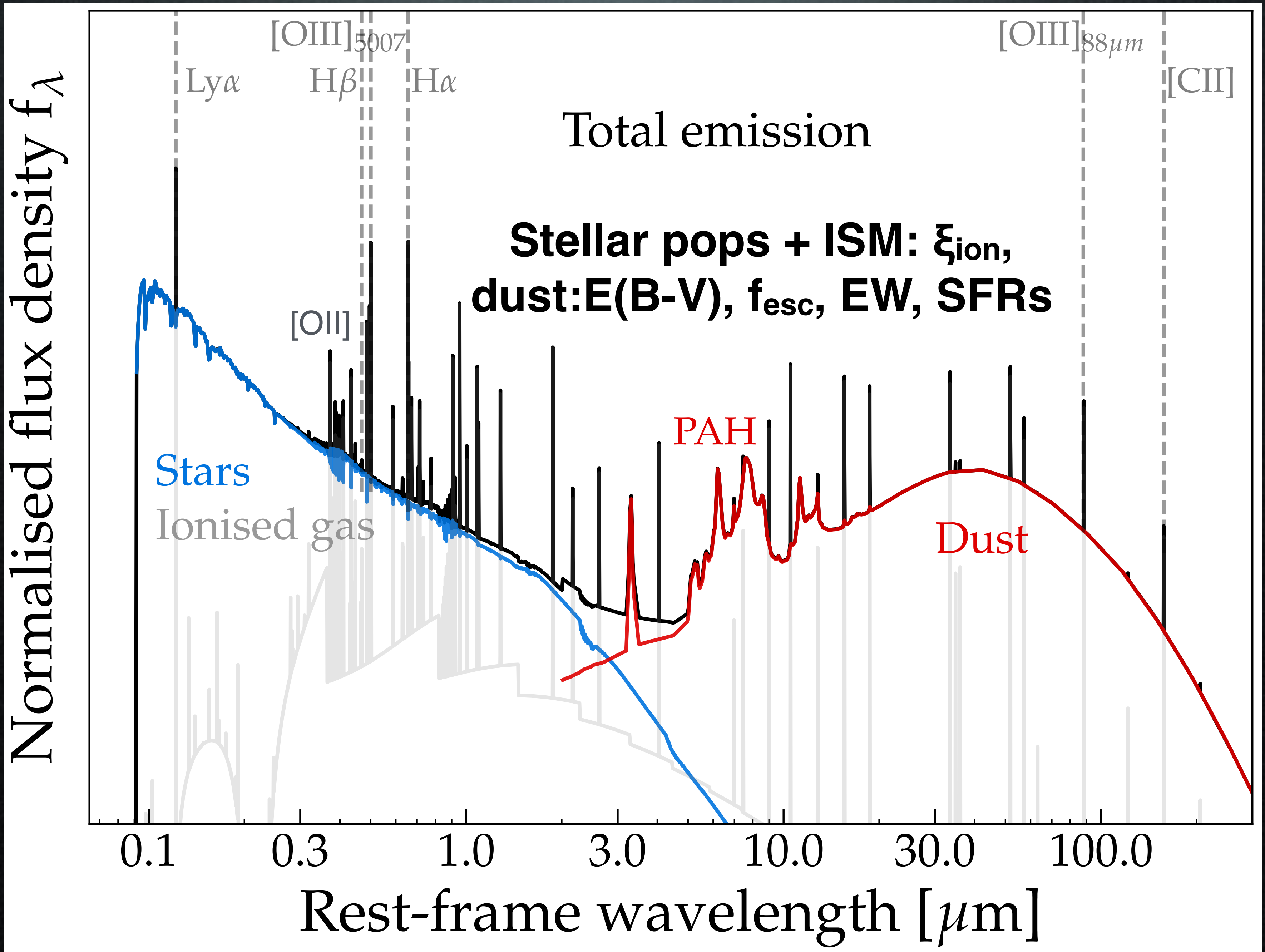
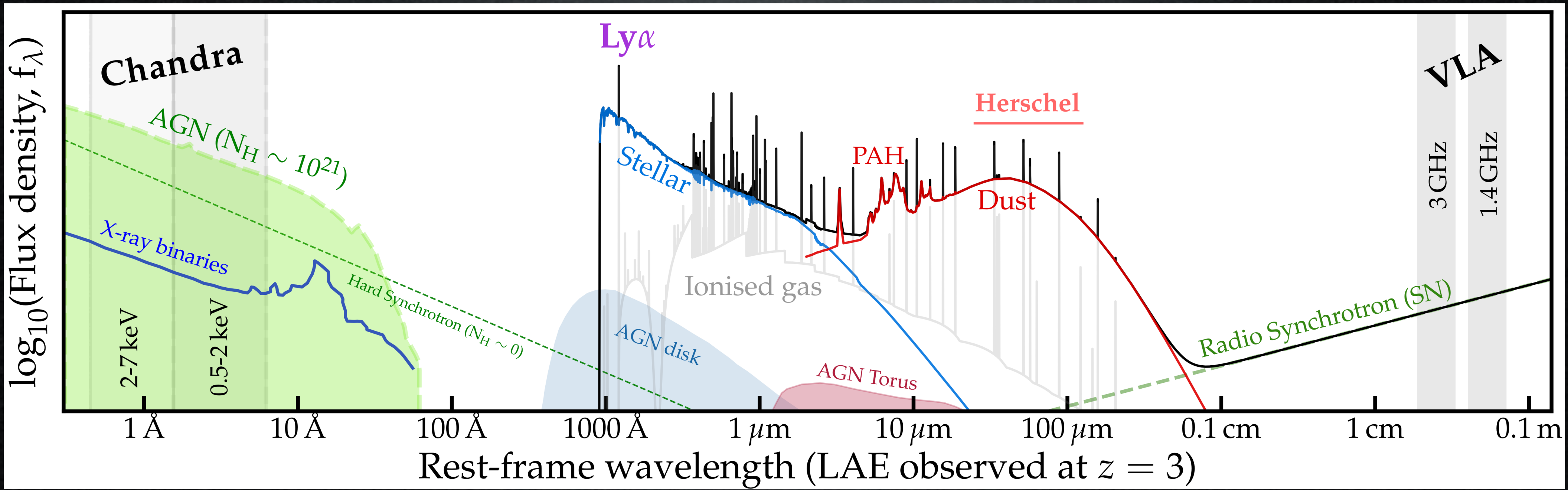
Unveiling the active early galaxy assembly with emission-lines



Meaningful progress requires access to and interpretation of all wavelengths/frequencies

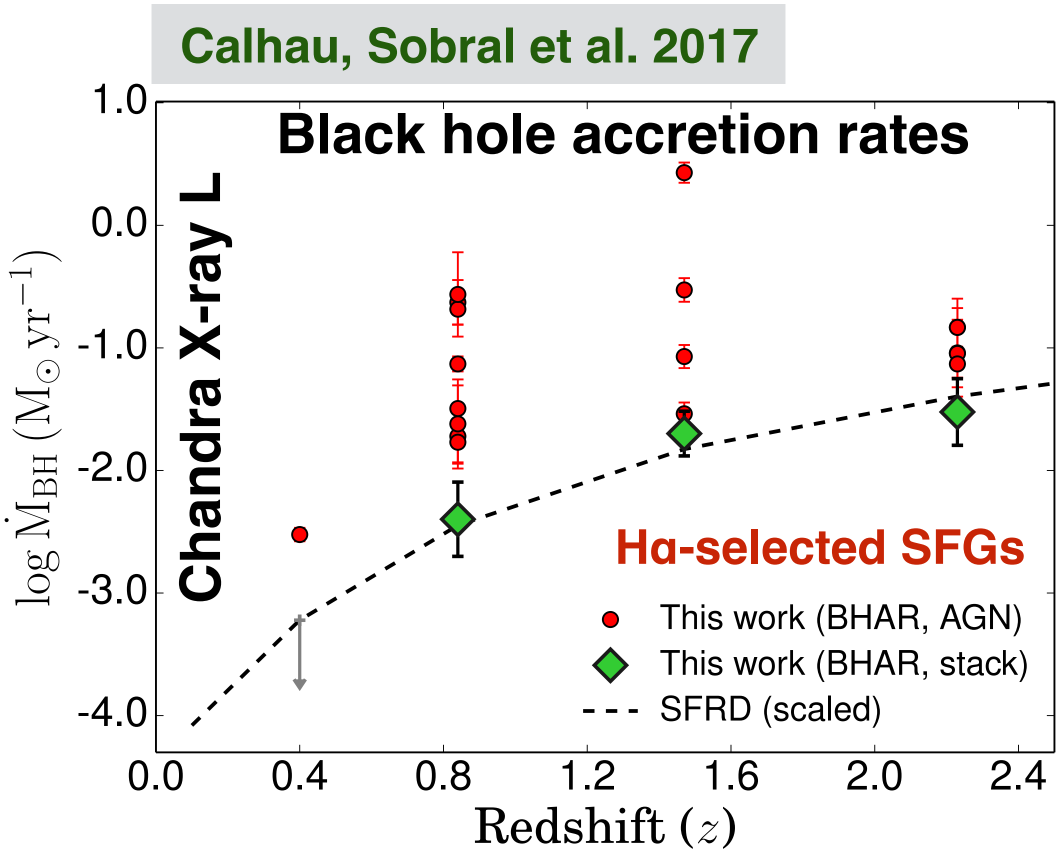
Science is much more motivating in the politics/science~0 regime

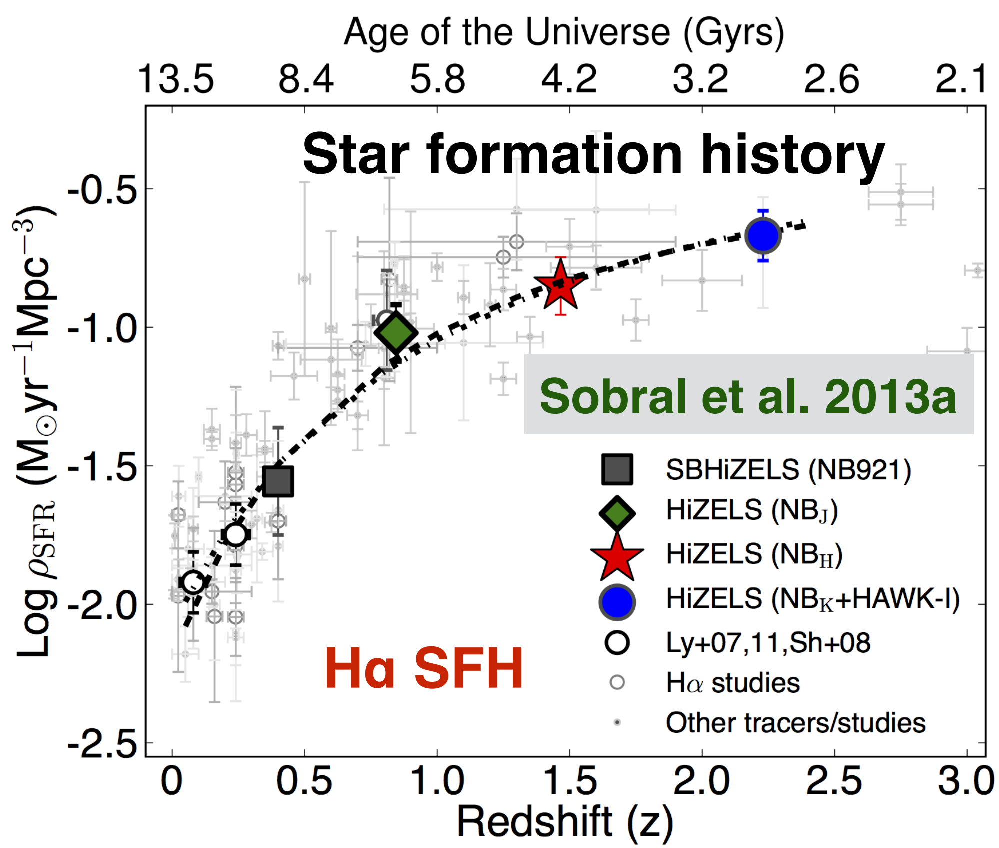
Redshift



Last 11 Gyrs: stellar mass and SMBH growth in SFGs

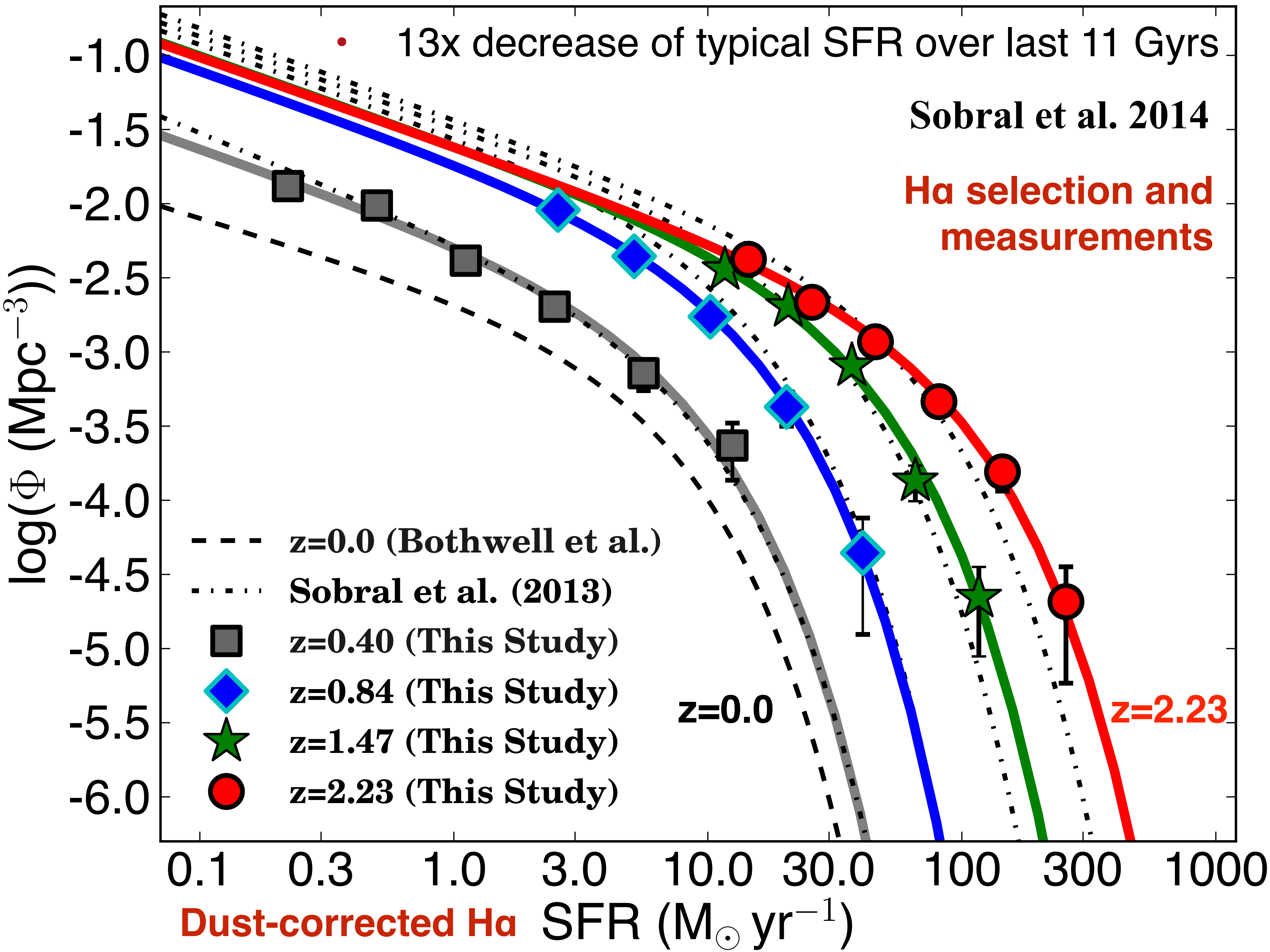
- Strong decline in star formation rate density since z~2.5
- Strong decline in typical black hole accretion rates: similar shapes, different normalisations: same feeding mechanism?





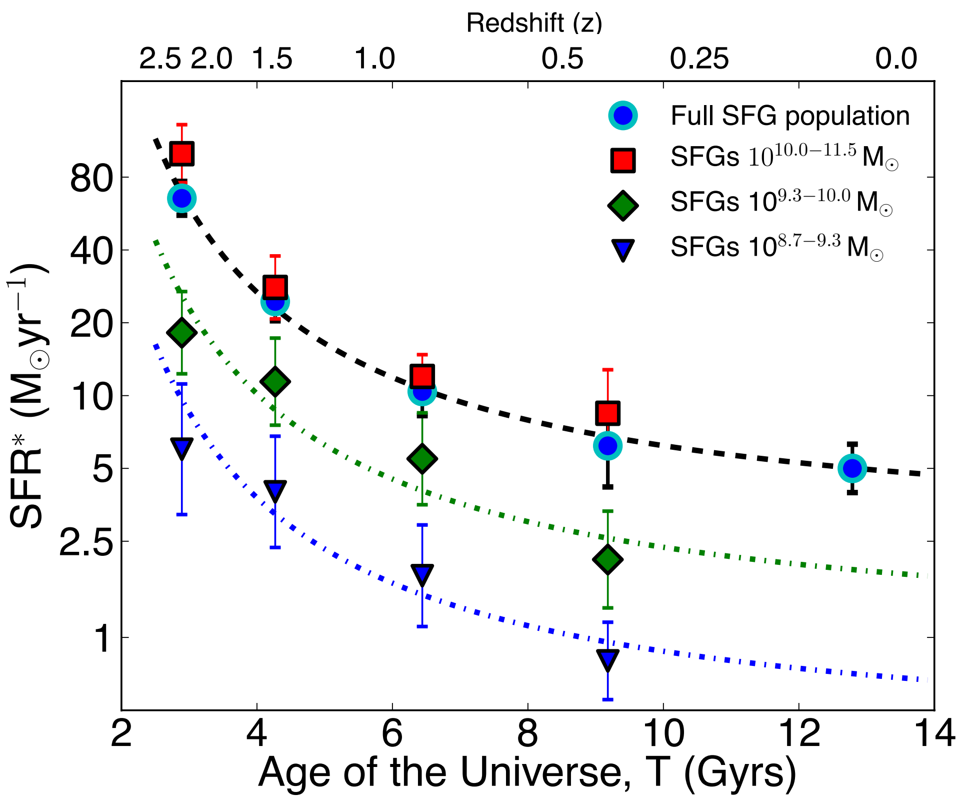
See also: Aird+2010; Lehmer+2013; Delvecchio+2014; Brandt & Alexander 2015; Stanley+2015 McAlpine+17; Geach+08; Sobral+13a,14,15a; Karim+11; Madau & Dickinson14; Bouwens+15

Hα SFR function: 11 Gyr decline of star forming galaxies

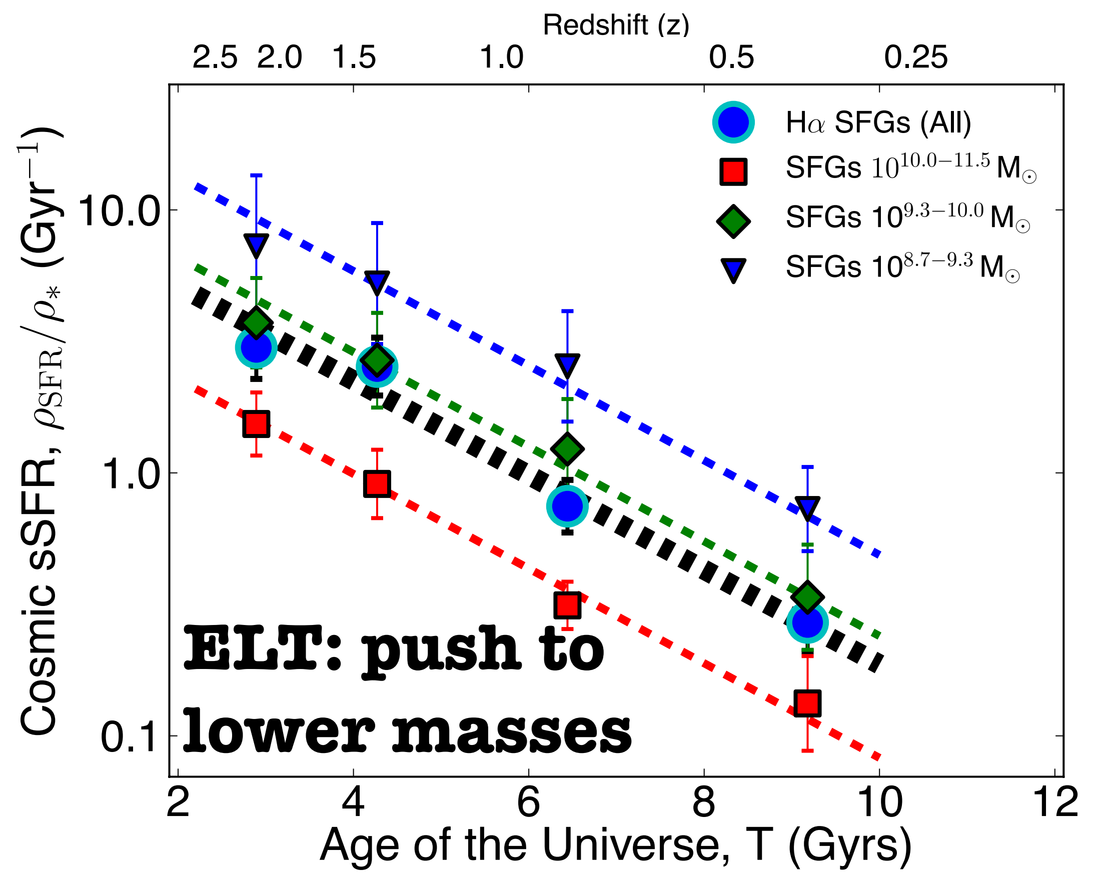


Strong SFR* decline with cosmic time towards z~0

- Decline of typical star formation rates of galaxies with cosmic time
- Decline of cosmic specific star formation rates with redshift for all masses



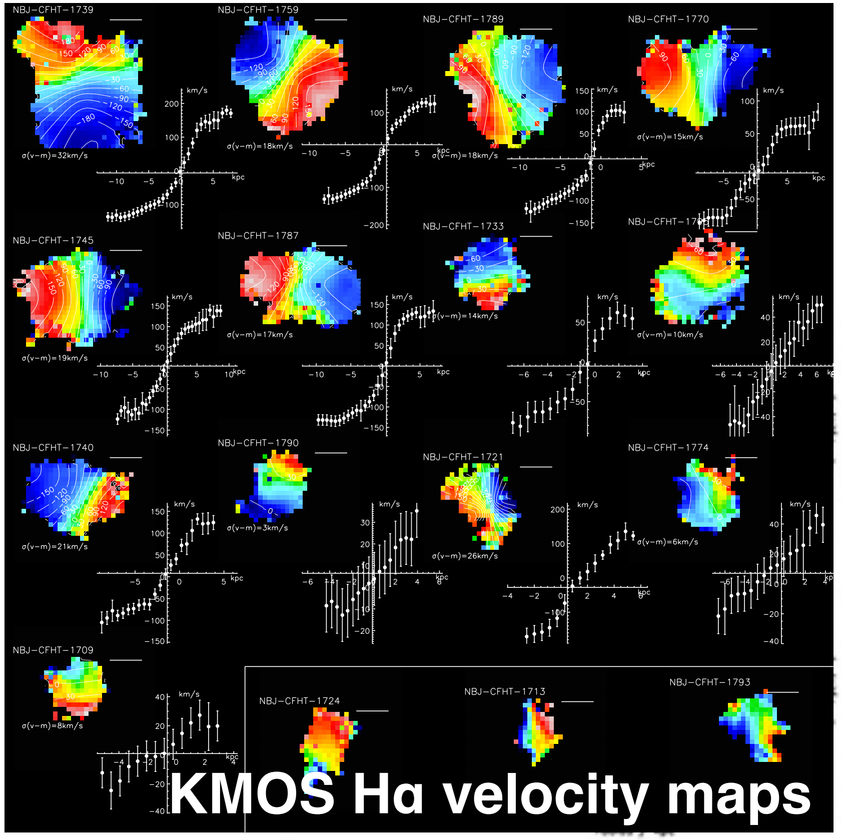
Decline at ALL masses



Koyama et al. 2013 **Decline at ALL environments** Sobral et al. 2014

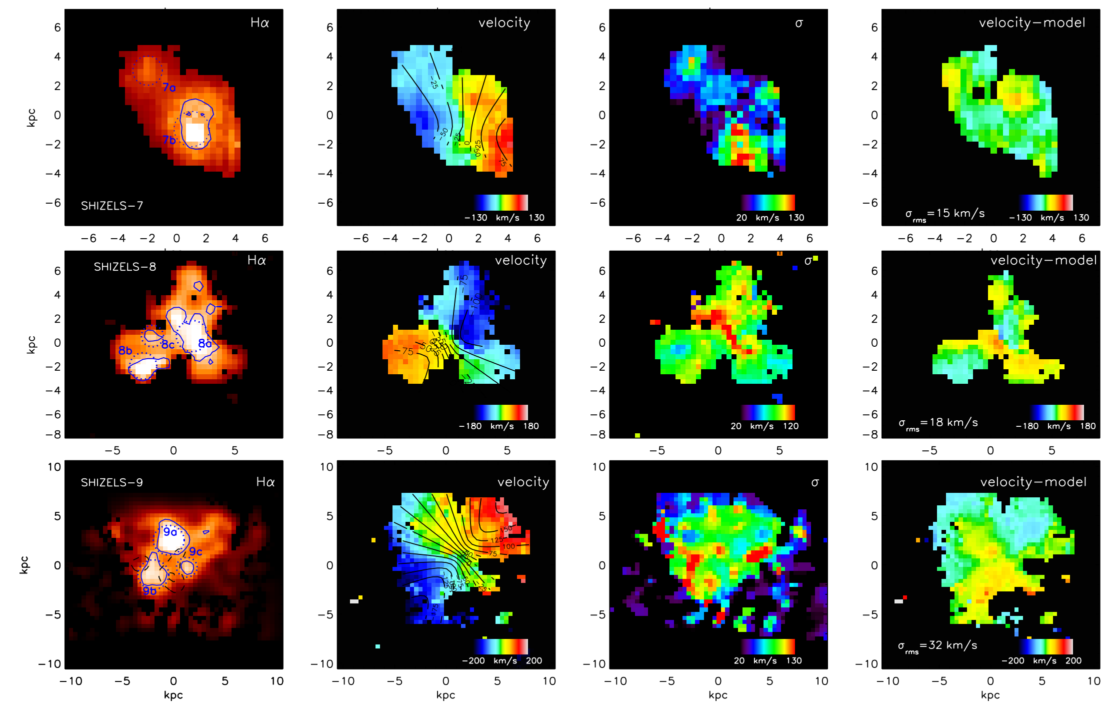
Hα-selected SFGs: resolved line ratios + dynamics

Turner+2017; Molina+2017, 2019

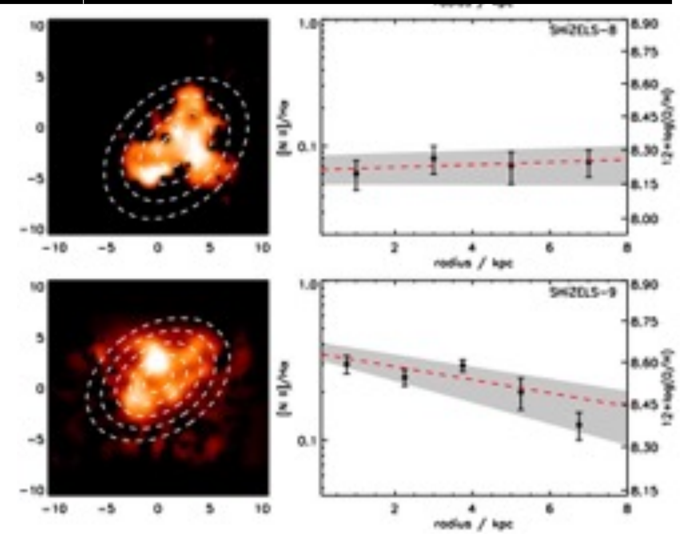


ELT: push to lower masses

Probe to scales of ~50-100pc



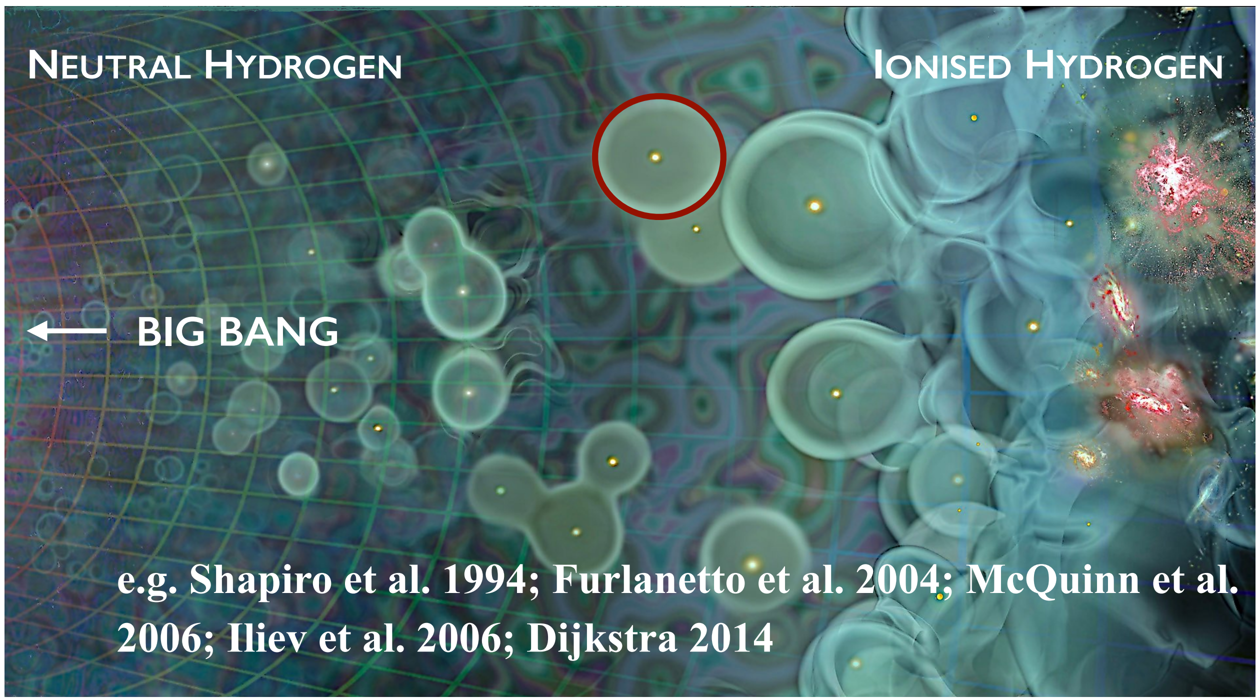
[NII]/H gradients

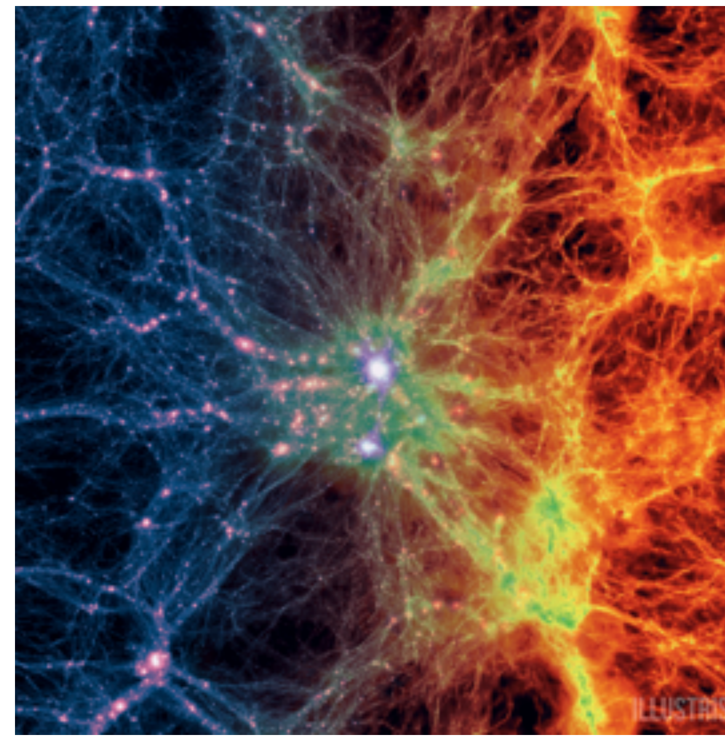


Swinbank+2012a,b; Sobral+2013b

Early galaxy and super-massive black hole formation

- What are the properties of the ISM and stars in early galaxies?
- How did galaxies/AGN re-ionise the Universe? Can we see it?
- Emission-lines (blind-selection): crucial for our understanding



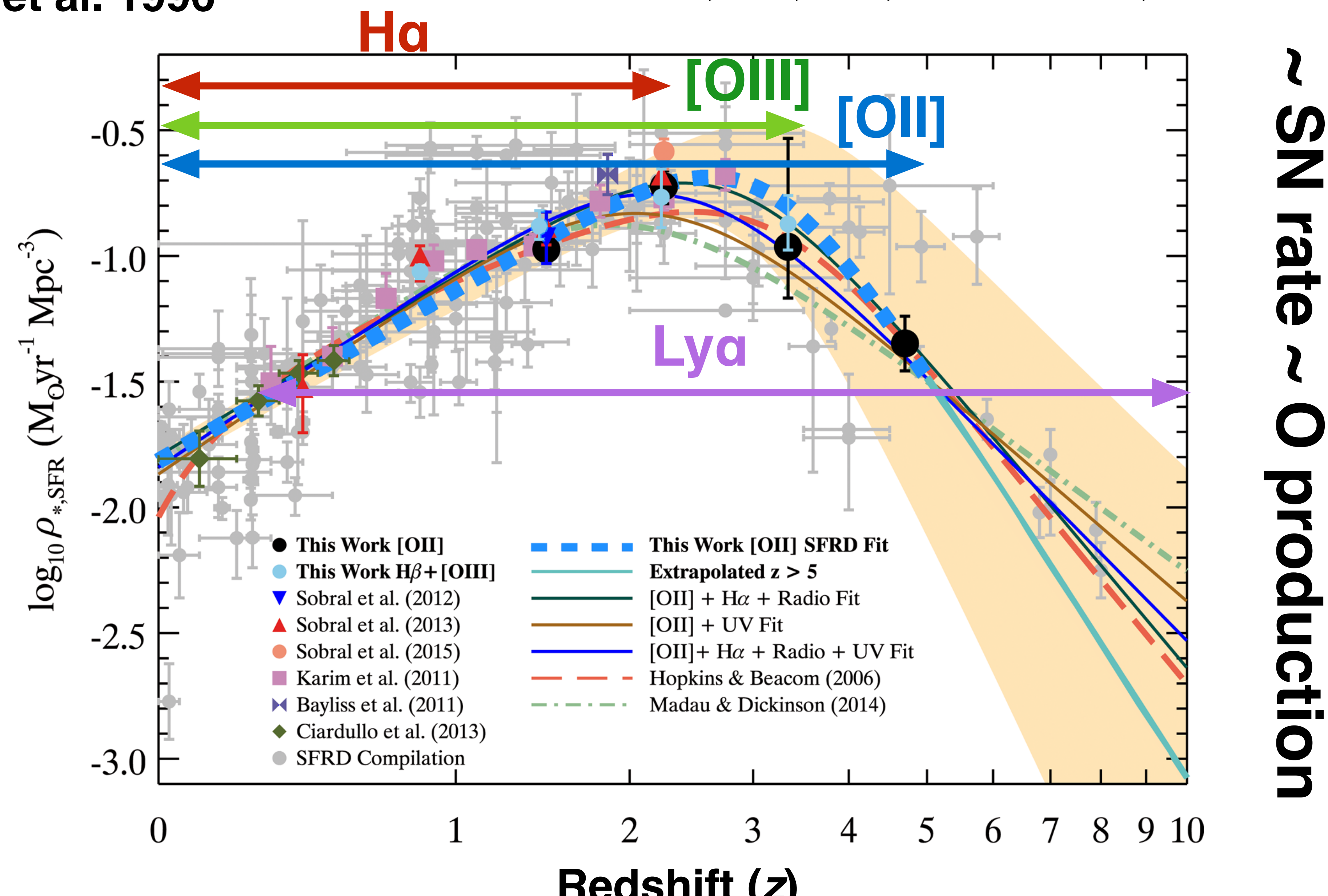


Observations crucial to test state-of-the-art models: e.g. Boylan-Kolchin et al. (2009); Hopkins et al. 2014; Vogelsberger et al. 2014; Schaye et al. 2015; Crain et al. 2015; Lacey et al. 2016.
Models important to make new predictions that can be tested: e.g. Matthee & Schaye 2018.

Star formation history of the Universe: emission-lines

Lilly et al. 1996

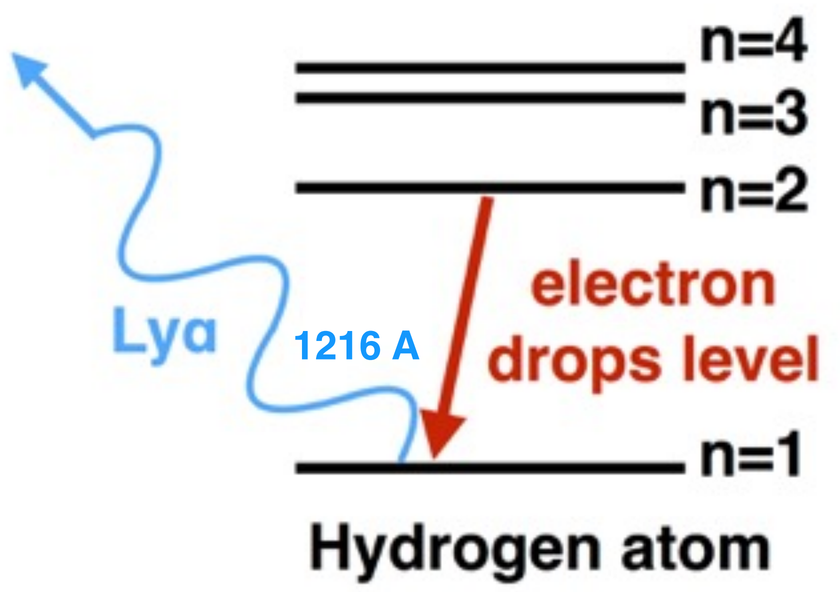
Sobral+12,13a,15b; Khostovan, Sobral+15

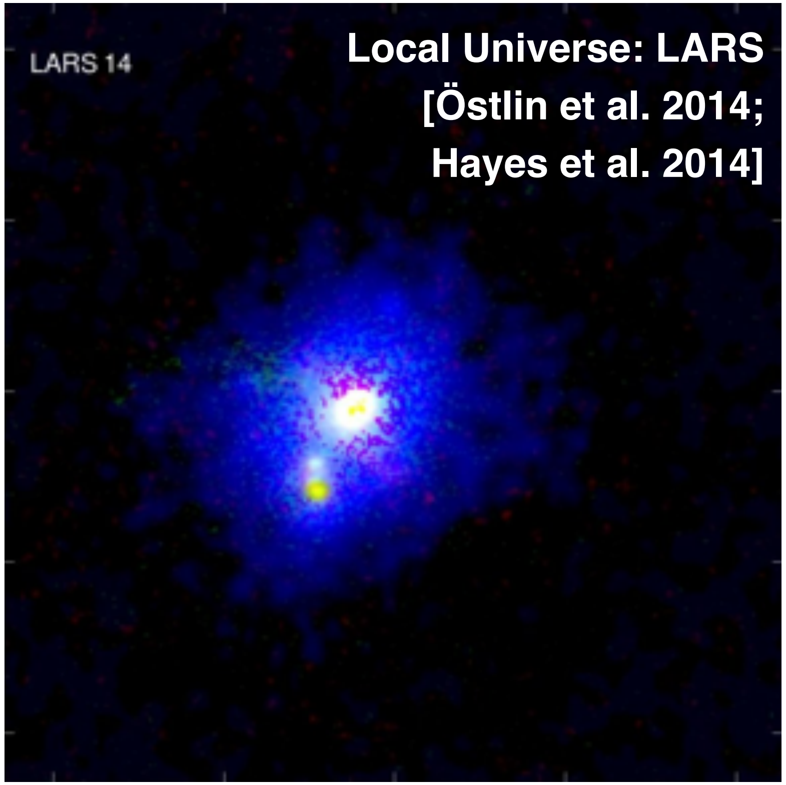


See also: Geach+08; Sobral+13a,14,15a; Karim+11; Madau & Dickinson14; Bouwens et al. 2015

Lyα is **still** the best spectroscopic tool at z>2…

- 1216 Å redshifts into optical at z > 2
- Intrinsically most luminous emission-line in HII regions
- Asymmetric shape + Lyman-break
- Also consequence of AGN activity





Coupled with other UV lines: NV, CIII], CIV, HeII, OIII]

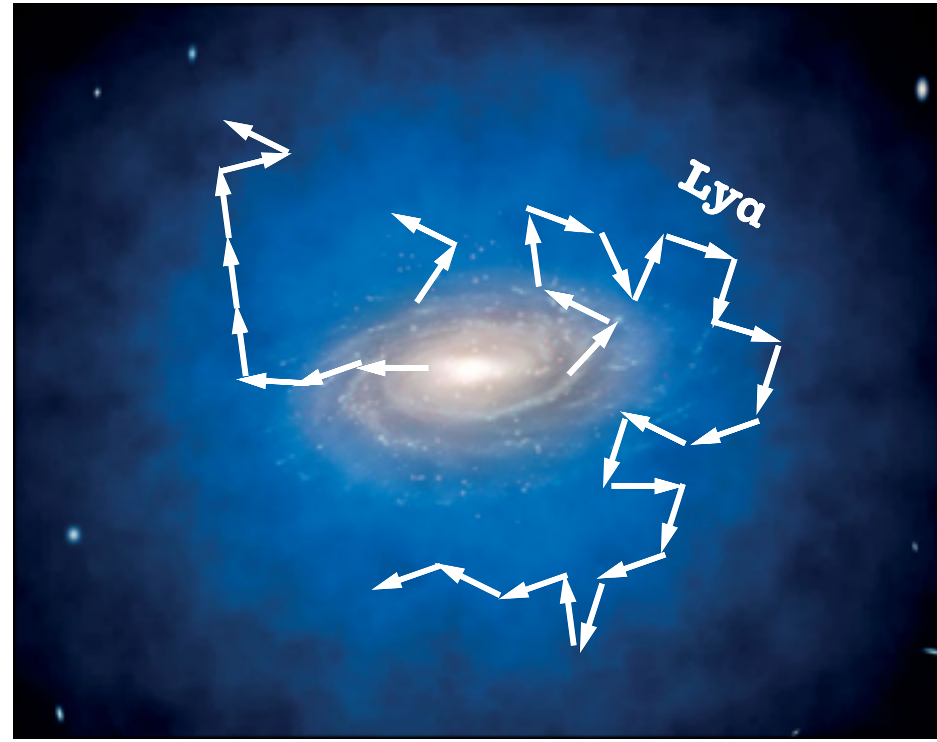
See Andra's talk and: Stroe, DS et al. 2017a,b; Stark+15,16;

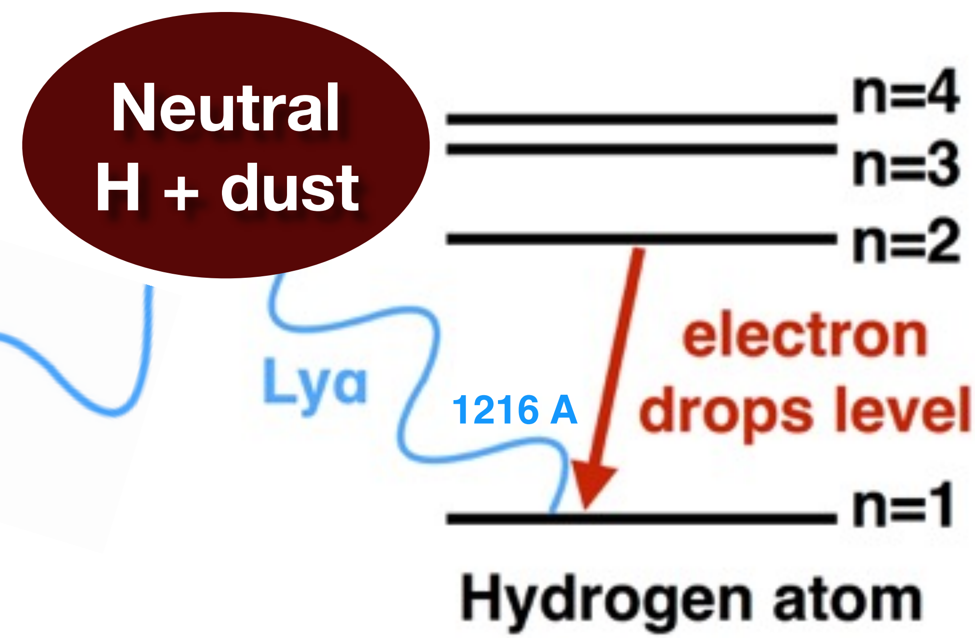
See e.g.: Humphrey+2007; Smith & Jarvis 2007; Ouchi+2008,2010; Matthee+2014, 2015,2017c; Nilsson+2009; Song+2014; Oteo+2015; Pentericci+2014; Hayes 2011; Dijsktra 2015; Verhamme+2015; Konno+2016; Harikane+18

Lyα may seem like a low hanging fruit… but not so easy to eat

(sometimes not easy to get)!

- … easily scattered and re-emitted: most photons escape at low surface brightness
- Easily absorbed in the inter-stellar medium and intergalactic medium.
- Escape fraction not well understood
- Neutral IGM affects Lyα - hard to use at z>6





$f_{esc,Ly\alpha} = f_{Ly\alpha} / (8.1\text{-}9.0\ f_{H\alpha})$ **Henry+15**

$f_{esc,\ Ly\alpha} = f_{Ly\alpha} / (8.7\ f_{H\alpha})$

Only a small fraction of Lyα photons escape: Hα can be used to measure it

e.g. Hayes et al. 2010

What do we need to make progress? Our wish list

- **Ideally: Hα + Balmer decrement + case B: predict Lyα vs observed**

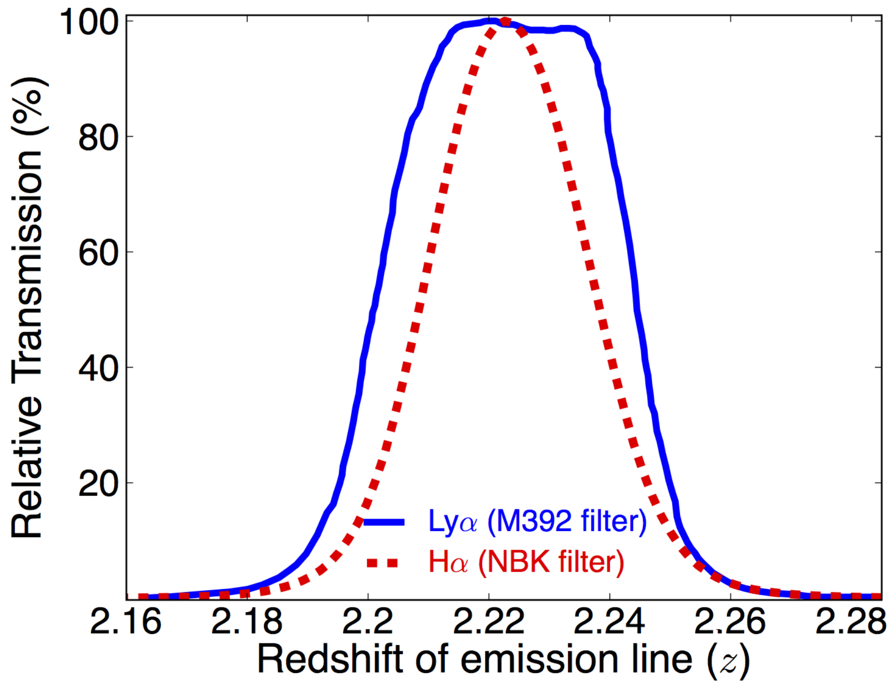
The **CALYMHA** survey: CAlibrating LYman-α with Hα

$$f_{\mathrm{esc,Ly}\alpha} = \frac{\mathrm{L_{Ly\alpha}}}{8.7\,\mathrm{L_{H\alpha}} \times 10^{0.4\times \mathrm{A_{H\alpha}}}}$$

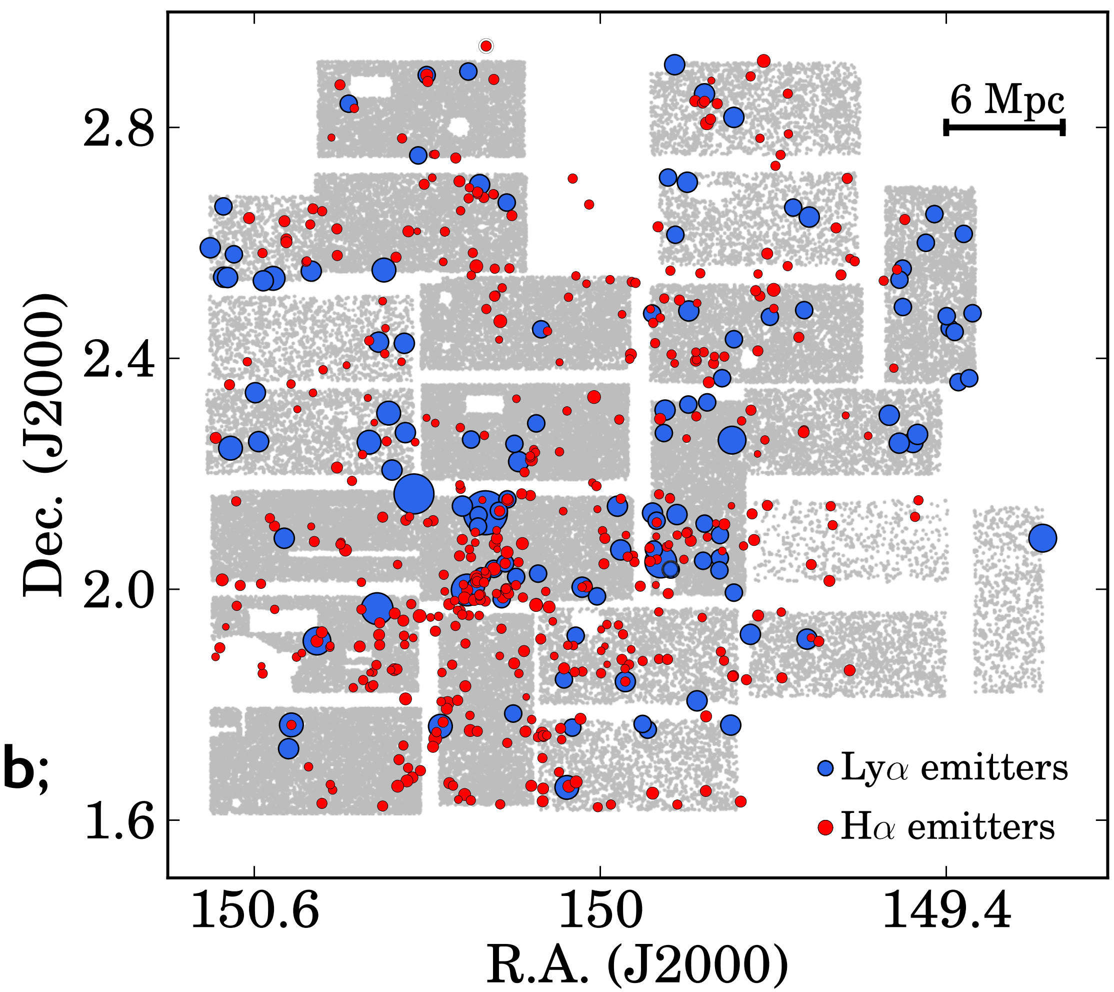
(PI: Sobral) INT@La Palma + CFHT @Mauna Kea

The CALYMHA survey: CAlibrating LYman-α with Hα

- Custom-made narrow-band filter. **50 nights INT + 8 nights CFHT** (PI: Sobral)
- **5 deg² deep double-blind matched Lyα-(CIV-OII-OIII)-Hα** (and LyC) survey.



Hα from HiZELS

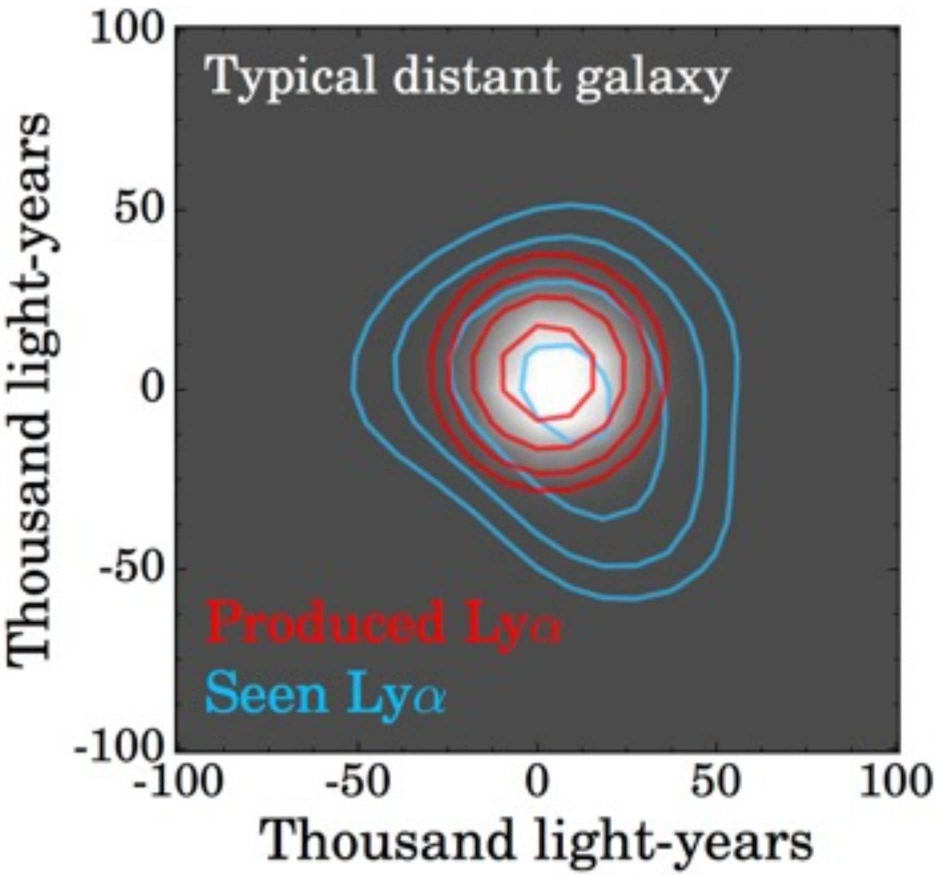


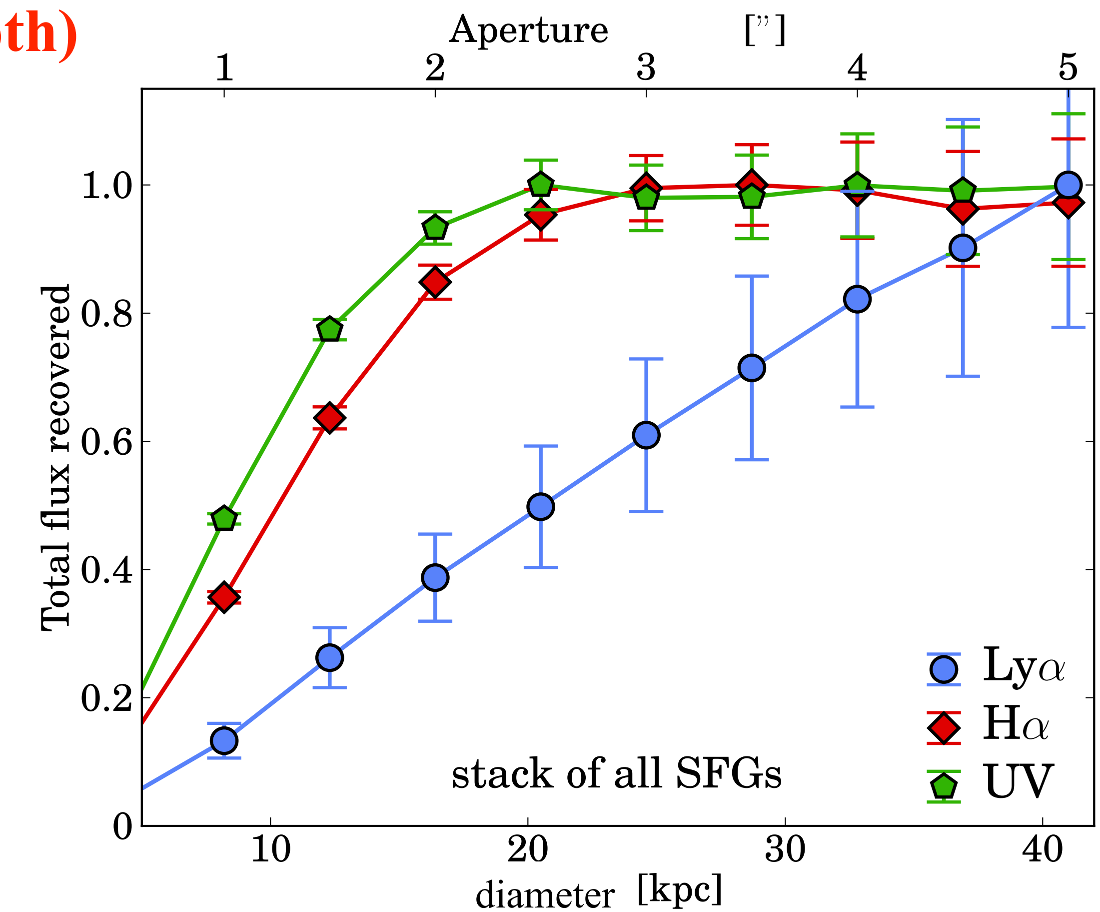
Matthee, Sobral et al. 2016, 2017a,b; Sobral, Matthee et al. 2017a; Stroe+2017a,b; Sobral+2018a

See also e.g. Hayes et al. 2010; Ciardullo et al. 2014; Oteo, DS et al. 2015

Extended (~40 kpc) Lyα emission in star-forming galaxies

Stack: 3000 hours (~MUSE-like depth)





see also Nelson+16; 3D-HST

Use Hα to predict Lyα luminosity then compare with observed Lyα

$f_{esc,\,Ly\alpha} = f_{Ly\alpha}/(8.7\ f_{H\alpha})$

- **Hα emitters: 1.6±0.5%** Lyα photons escape at < 25 kpc

$f_{esc,Ly\alpha} = f_{Ly\alpha}/(8.1\text{-}9.0\ f_{H\alpha})$

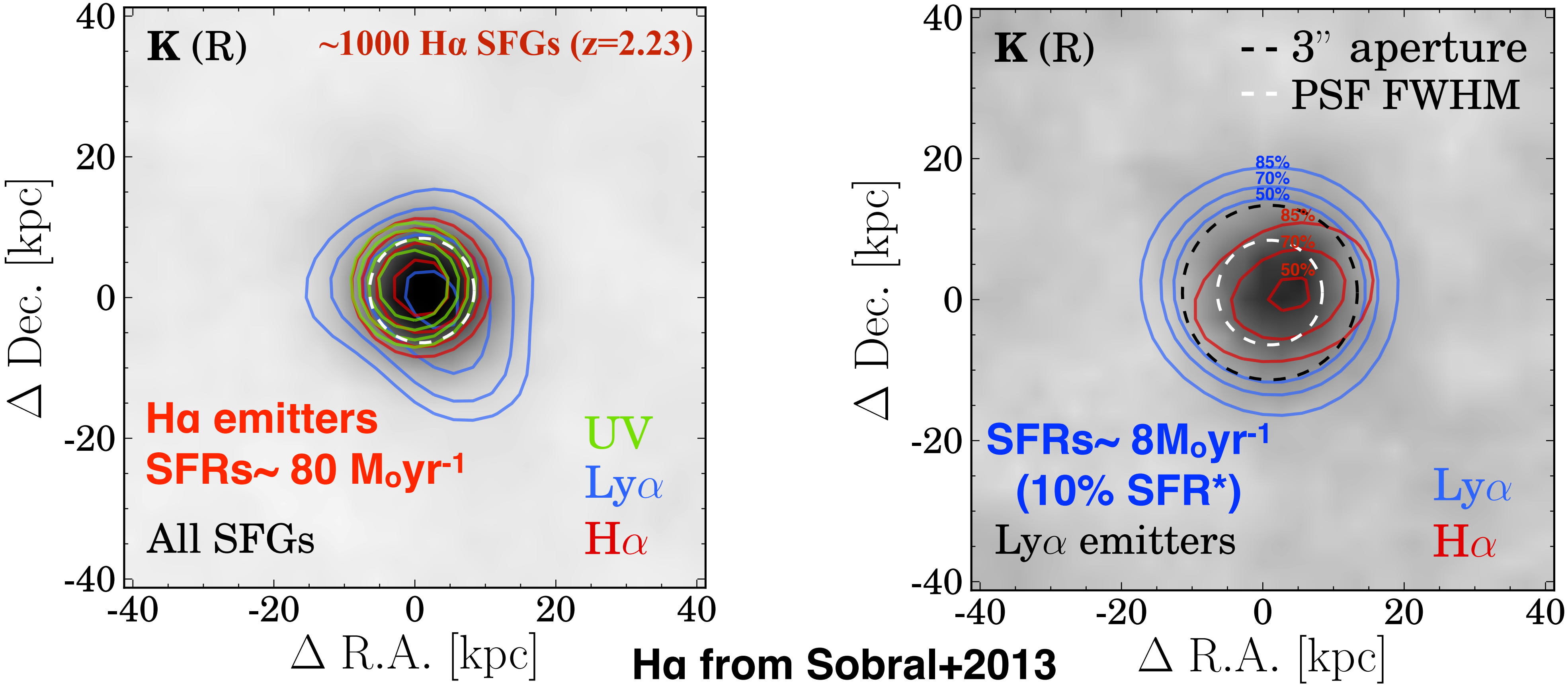
Matthee, Sobral+16a, Sobral, Matthee+17a

Extended (~40 kpc) Lyα emission in star-forming galaxies

Matthee, Sobral+16a, Sobral, Matthee+17a

Stack: 3000 hours (~MUSE-like depth)

~200 Lyα emitters (z=2.23)



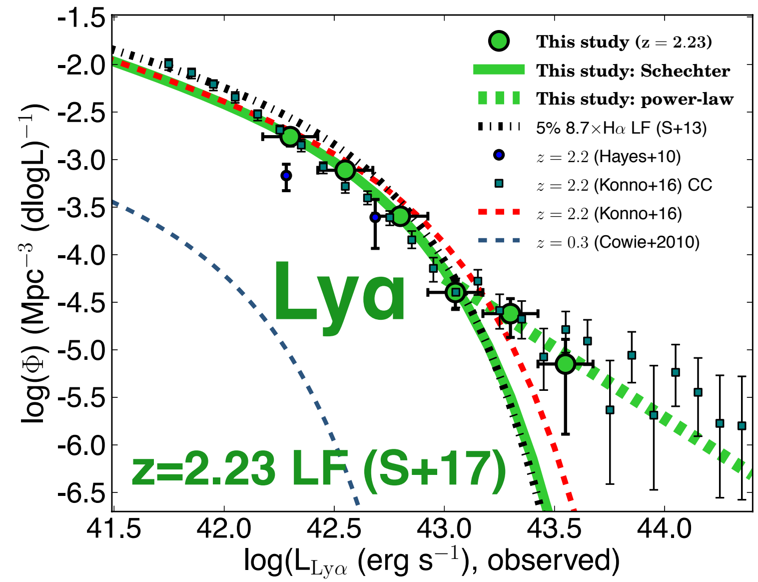
Hα from Sobral+2013

Use Hα to predict Lyα (intrinsic) luminosity then compare with observed luminosity in Lyα

Global Lyα escape fraction from SFGs at z=2.23 (Hα)

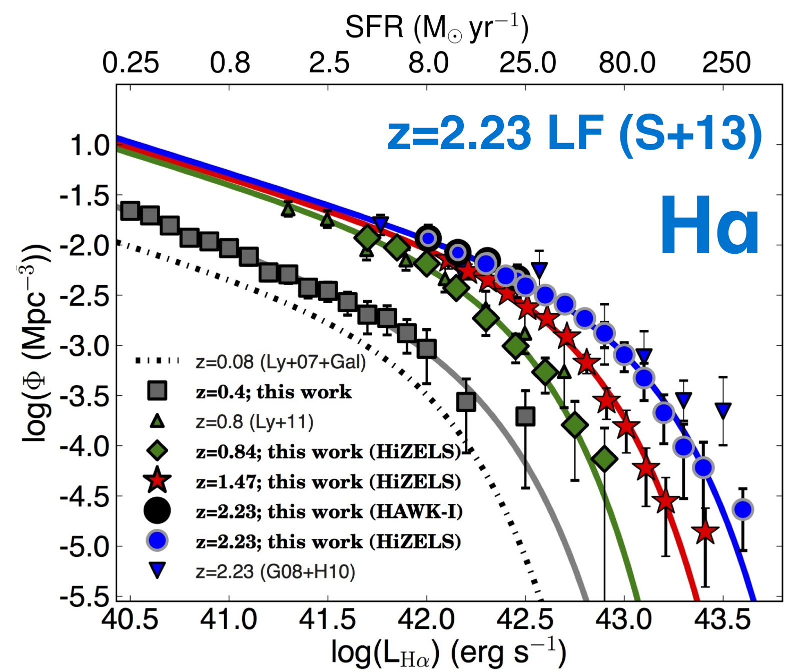
The CALYMHA survey: Lyα luminosity function and global escape fraction of Lyα photons at z = 2.23*

David Sobral[1,2]†, Jorryt Matthee[2], Philip Best[3], Andra Stroe[4]‡, Huub Röttgering[2], Iván Oteo[3,4], Ian Smail[5], Leah Morabito[2], Ana Paulino-Afonso[6,7]
[1] *Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK*
[2] *Leiden Observatory, Leiden University, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands*



- Global Lyα f_{esc}: **5.1±0.2%** for <25 kpc
- Global Lyα f_{esc}: **8.4±0.4%** for <40 kpc

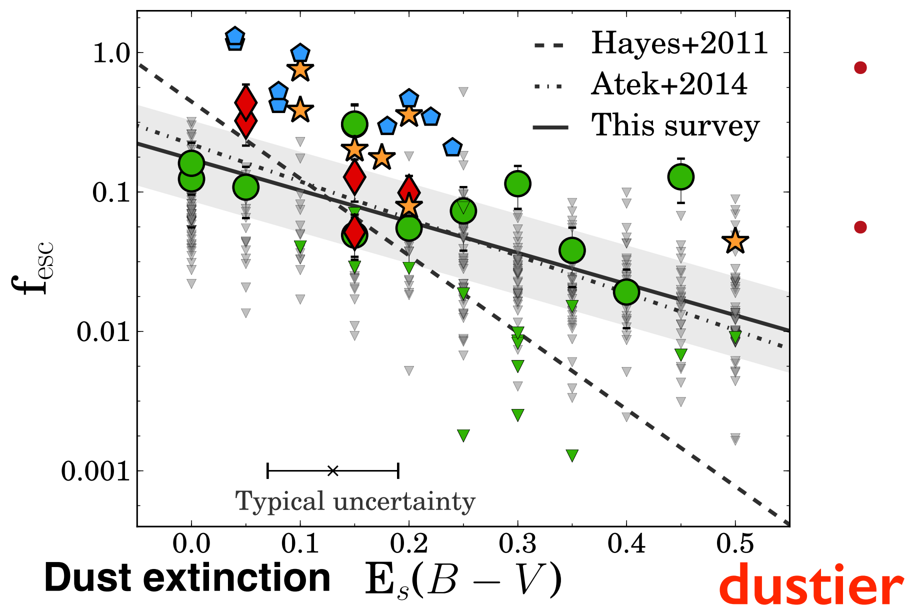
- Hα emitters: f_{esc} **1.6±0.5%** (<25 kpc)
- Lyα emitters: f_{esc} **37±7%** (<25 kpc)
- Most Lyα emitters consistent with up to Lyα f_{esc} ~100% to even larger radii



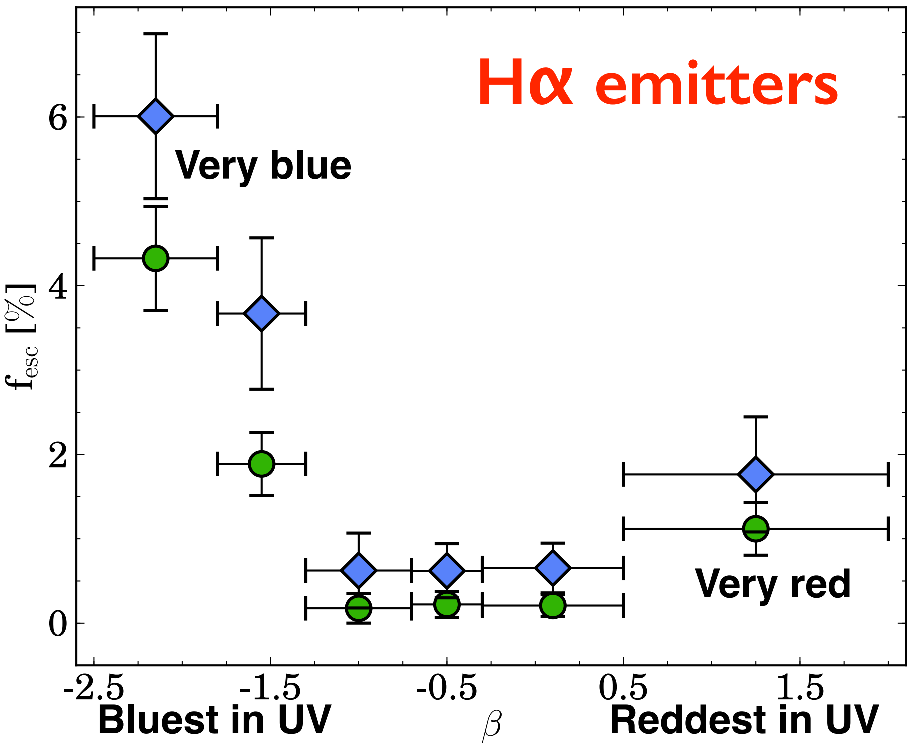
Matthee, Sobral et al. 2016; Matthee, Sobral et al. 2017a; Sobral, Matthee et al. 2017a; Sobral+2013

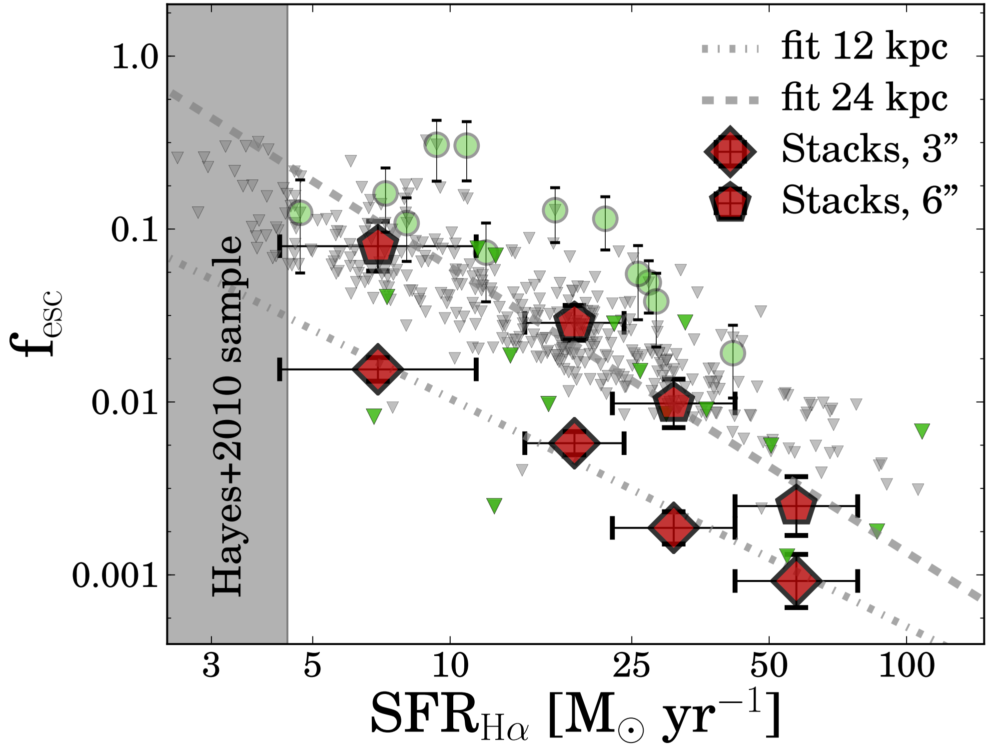
Escape of Lyα photons: what does it depend on at high z?

Matthee, Sobral et al. 2016



- Preferential escape of Lyα: **low to dust free star-forming galaxies**
- **But:** some heavily dust obscured sources with high escape fractions (e.g. sub-mm galaxies)





- Preferential escape from ultra-blue but also very red. Escape higher for low SFRs

Simplest predictor of Lyα escape fraction: Lyα EW_0

Sobral & Matthee 2019, A&A, 623, A157

Predicting Lyα escape fractions with a simple observable*

Lyα in emission as an empirically calibrated star formation rate indicator

David Sobral[1,2**] and Jorryt Matthee[2,3]

Measured from Lyα/Hα, not Lyα/UV

Measure for z~0 to z~2.6:

$$f_{\rm esc,Ly\alpha} = \frac{L_{\rm Ly\alpha}}{8.7\,L_{\rm H\alpha} \times 10^{0.4 \times A_{\rm H\alpha}}}$$

Simplest way to estimate without Hα:

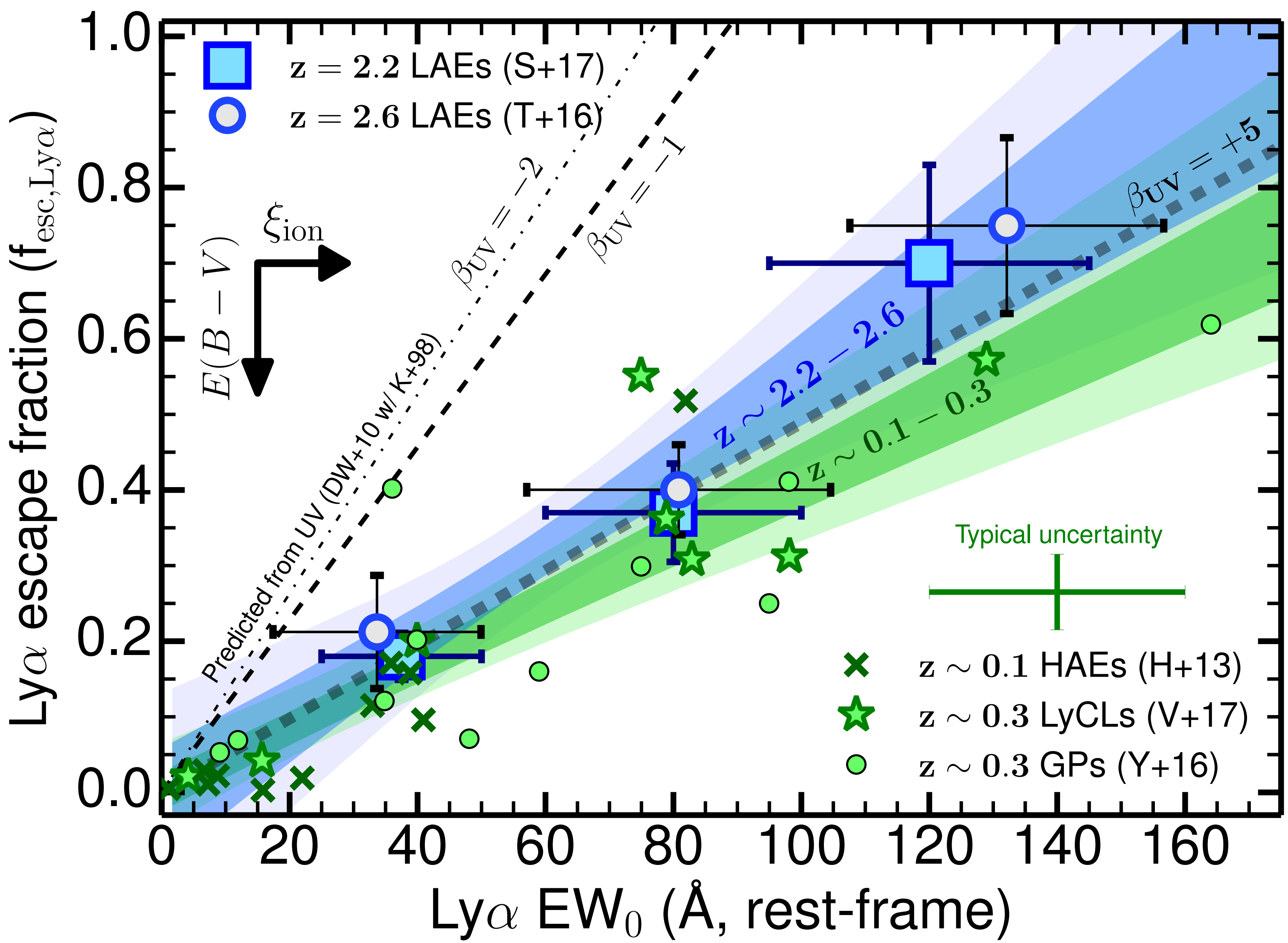
$$f_{\rm esc,Ly\alpha} = 0.0048^{+0.0007}_{-0.0007}\,{\rm EW}_0 \pm 0.05 \quad [\,0 \leq {\rm EW}_0 \leq 160\,\text{Å}].$$

Simplest predictor of Lyα escape fraction: EW_0

- Not evolving from z~0 to z~2.6

Sobral & Matthee 2019, A&A, 623, A157

Measured from Lyα/Hα, not Lyα/UV



See also: Verhamme+17 (z~0) Sobral, Matthee+2017 (z~2) and Harikane+17 (z=4.8)

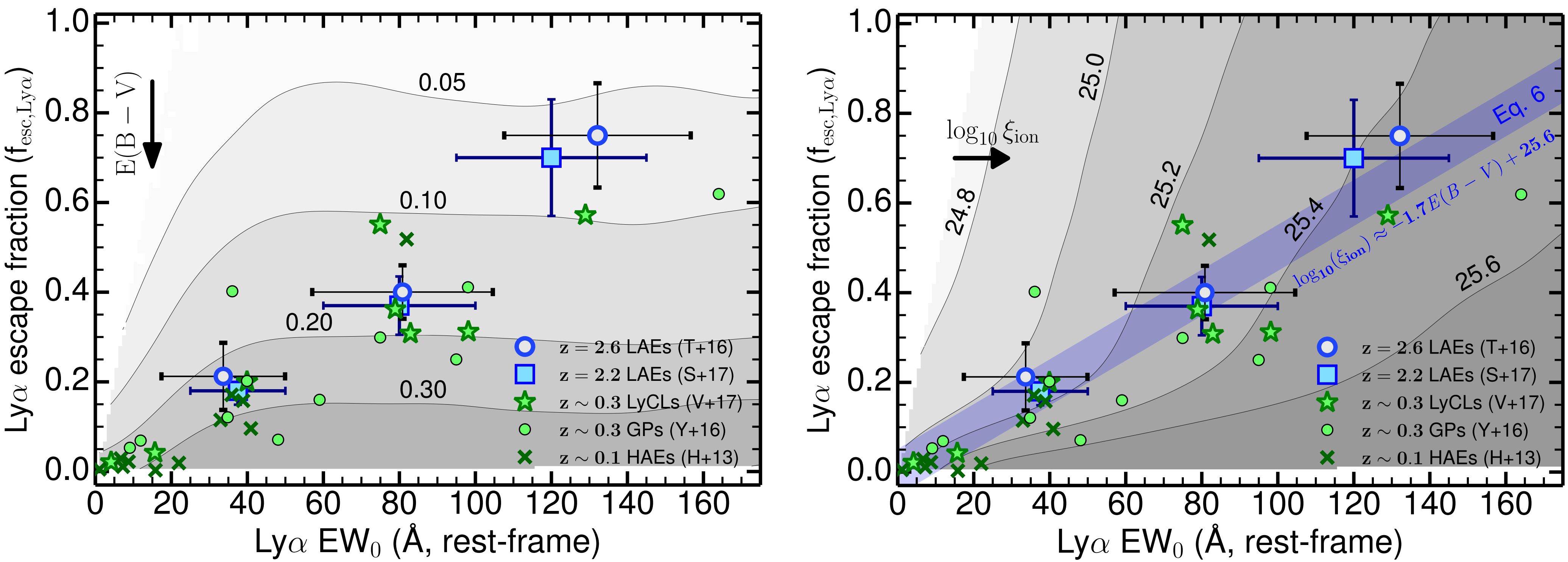
What does this mean physically? Dust-Ionisation eff.

Implies LAEs have high ionisation efficiencies and low E(B-V)

$$f_{esc,Ly\alpha} = \left(\frac{1.152^{-\beta-2}}{76}\mathrm{EW}_0\right)\frac{1.3\times10^{25}}{\xi_{ion}}10^{-0.4A_{UV}}$$

Highest EW with lowest E(B-V) and highest ξ_{ion} (LyC/UV)

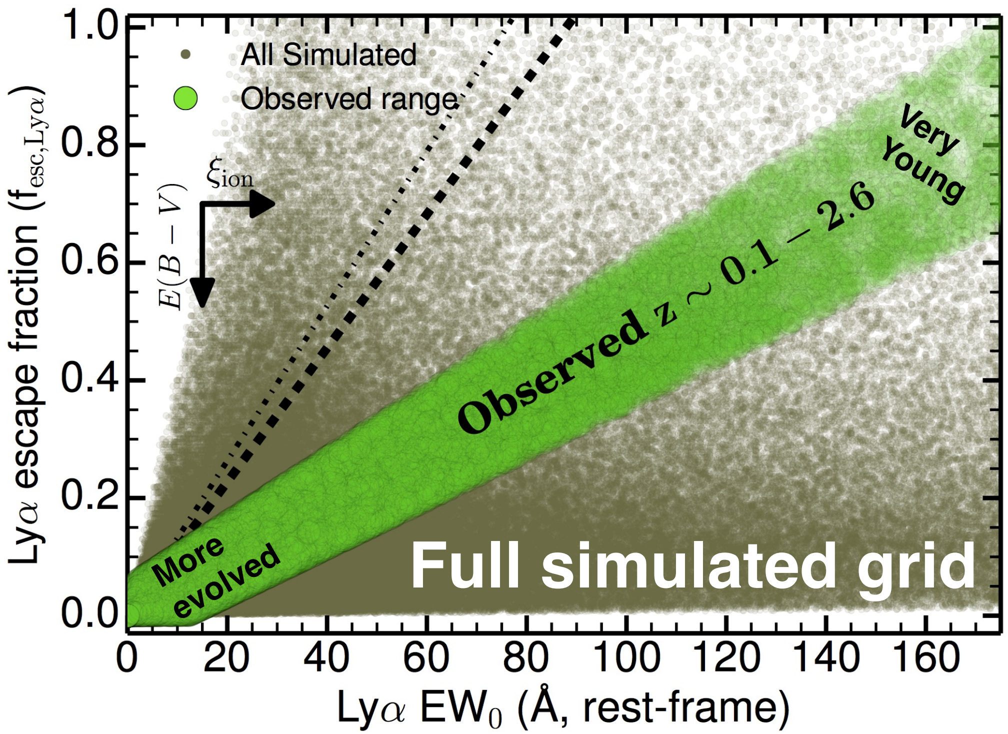
Sobral & Matthee 2019, A&A, 623, A157

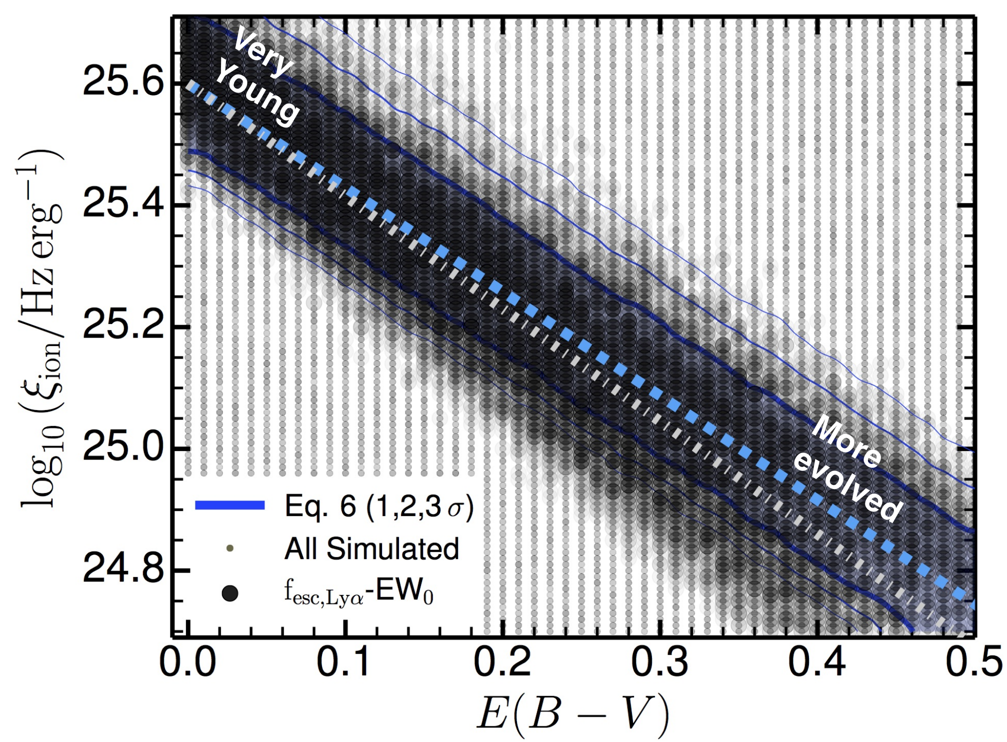


What does this mean physically?

The observed relation between escape fraction and EW implies a tight sequence between E(B-V) and ξ_{ion}.

Full grid available >> observed range (real) >> implications





$$f_{esc,Ly\alpha} = \left(\frac{1.152^{-\beta-2}}{76}\mathrm{EW}_0\right)\frac{1.3\times10^{25}}{\xi_{ion}}10^{-0.4A_{UV}}$$

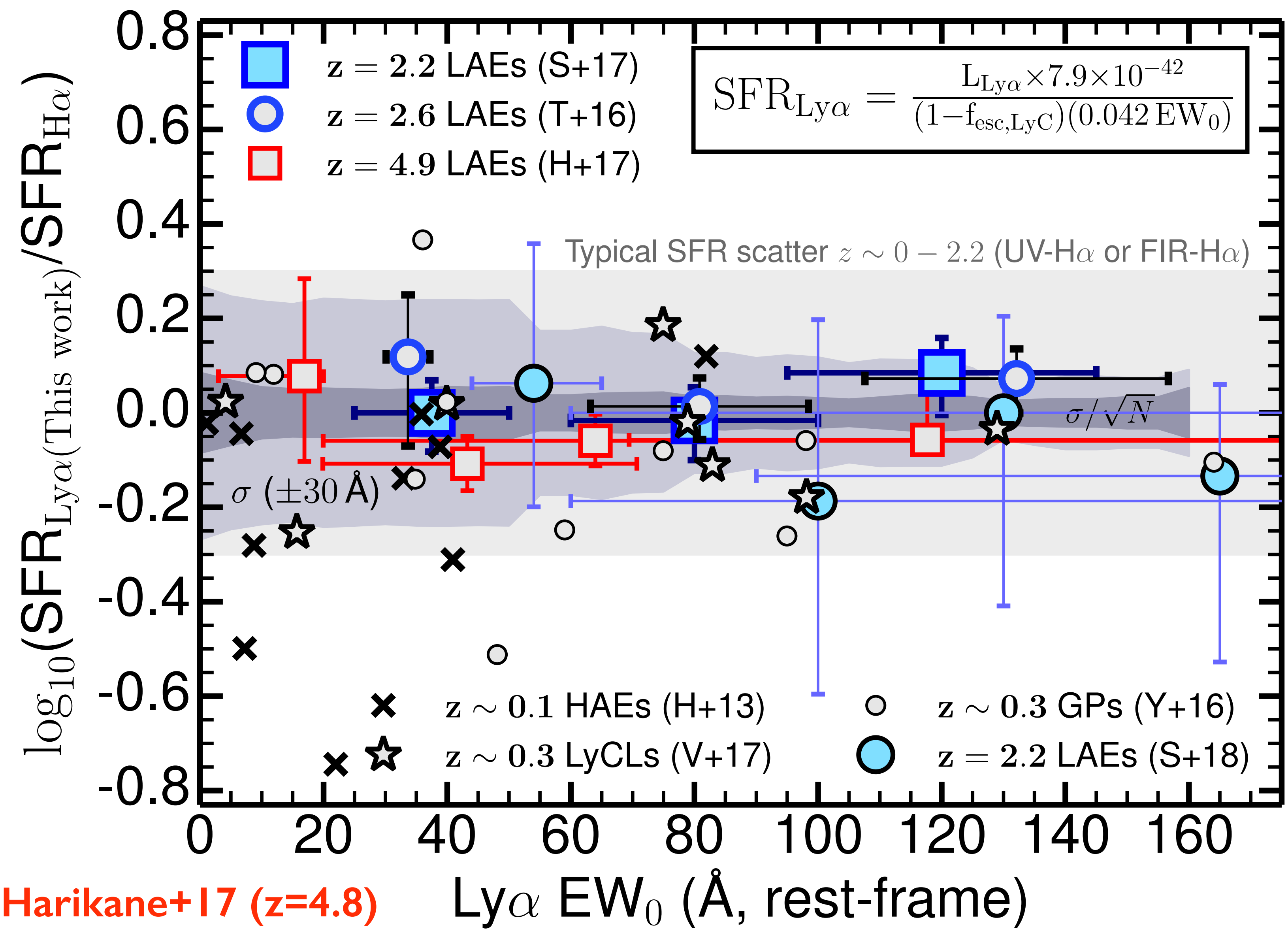
The Main-Sequence of LAEs

Sobral & Matthee 2019, A&A, 623, A157

Lyα as an empirically calibrated LyC and SFR indicator

$$Q_{ion,Ly\alpha}\,[s^{-1}] = \frac{L_{Ly\alpha}}{c_{H\alpha}\,(1 - f_{esc,LyC})\,(0.042\,EW_0)}$$

Sobral & Matthee 2019, A&A, 623, A157



See also Harikane+17 (z=4.8)

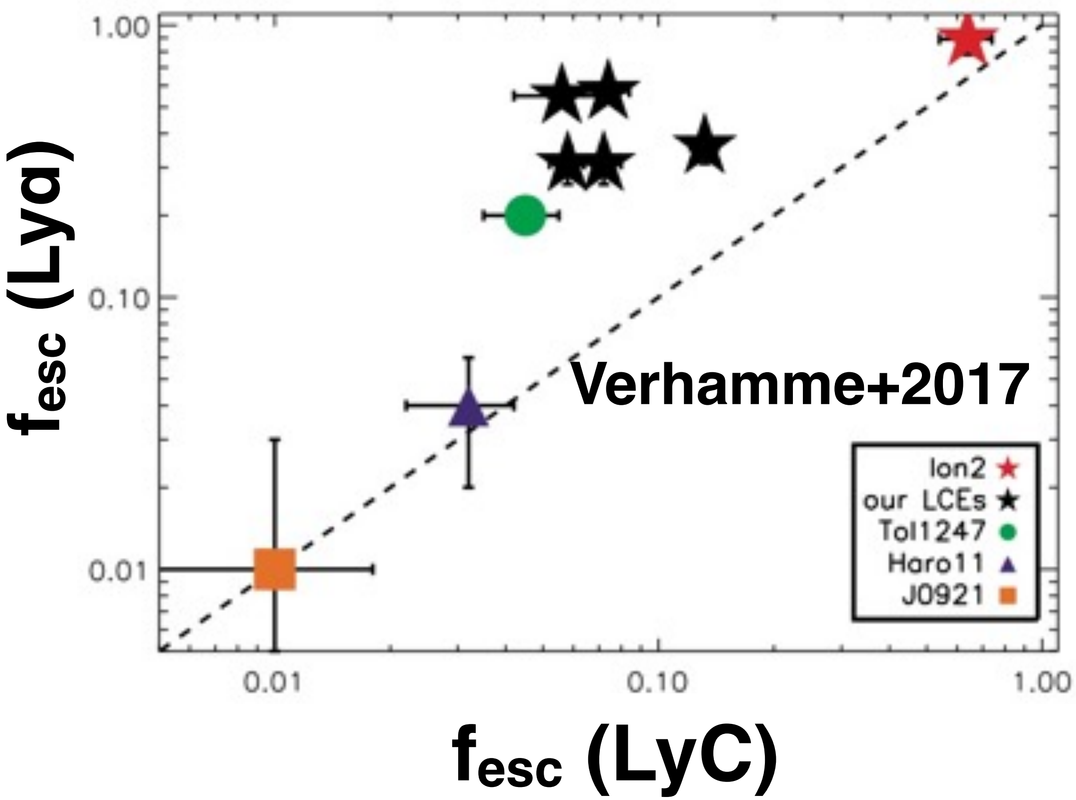
Why should we care even more? Lyα-LyC connection

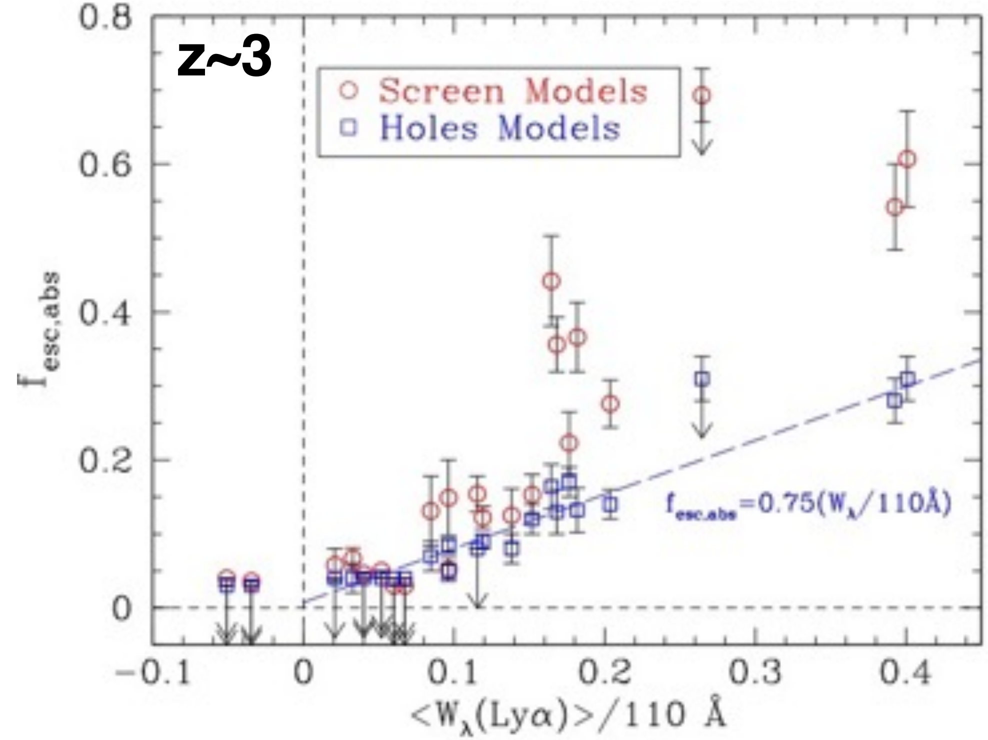
- **Lyα emitters have high ξ_{ion} + steep faint-end slope + high Lyα escape fraction + Lyα-LyC connection slope** suggests they are the most leaking

z~0-0.3

See also e.g. Fletcher+2018

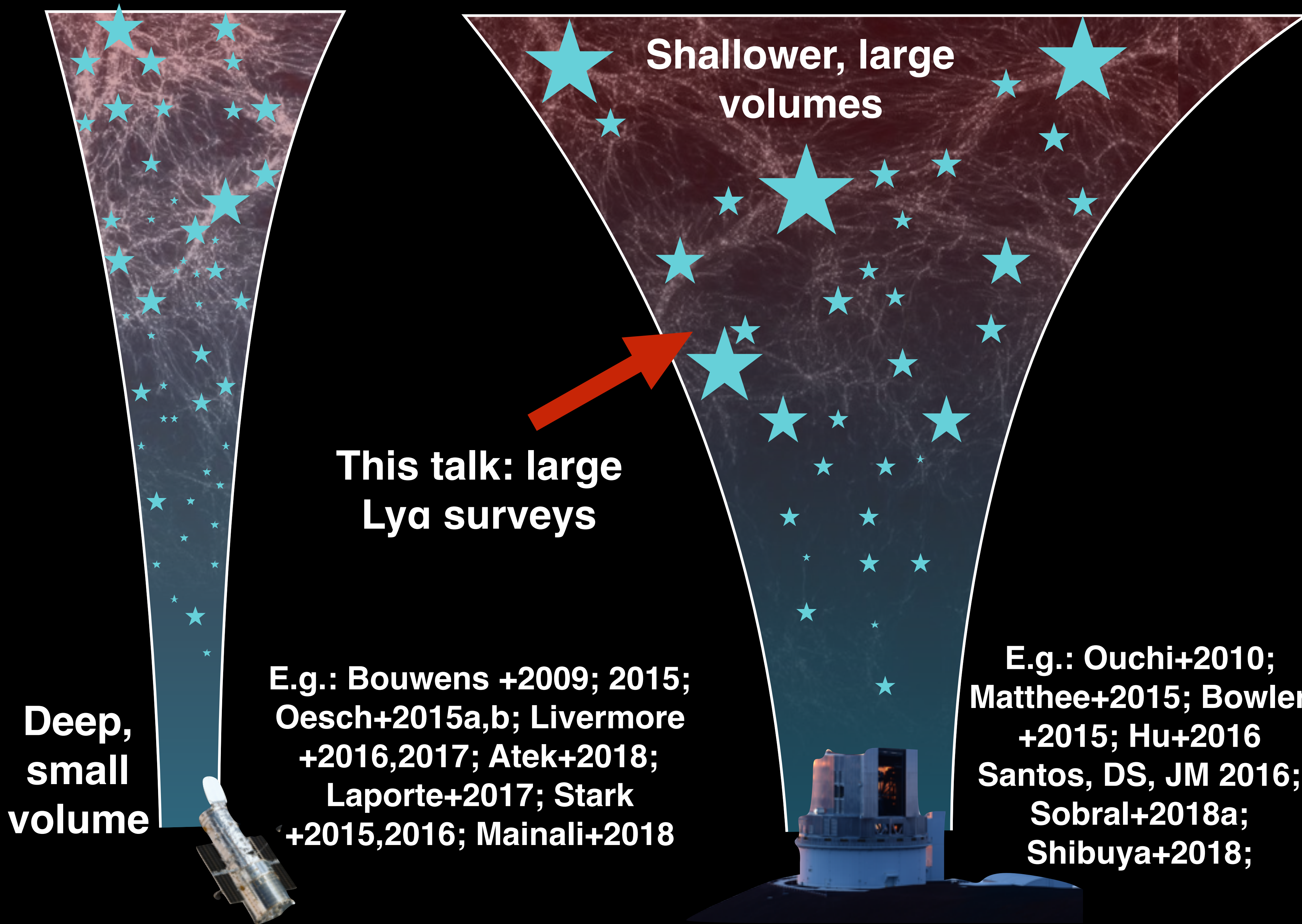
Steidel+2018



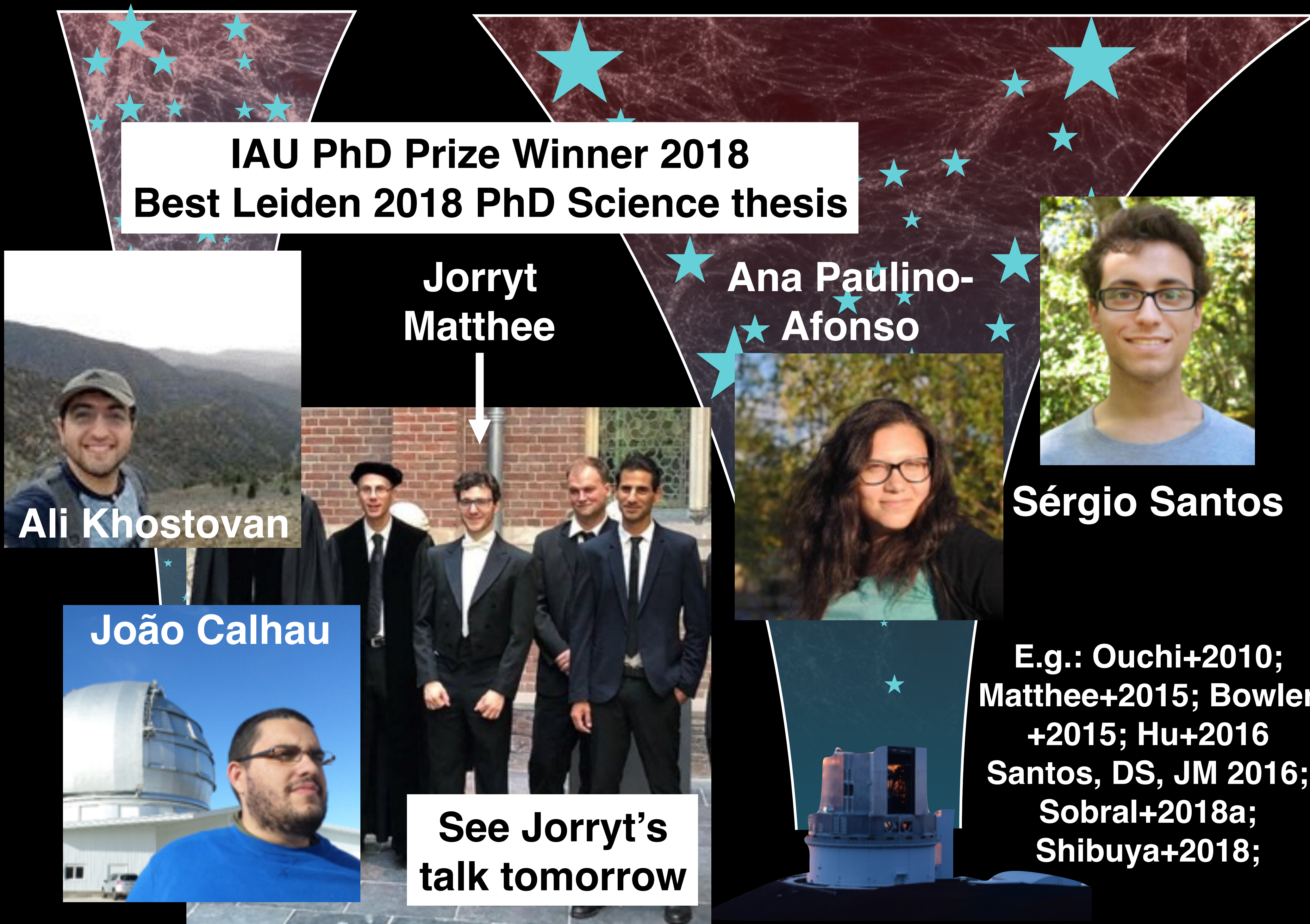


- If no Lyα comes out, no LyC comes out (e.g. **Steidel+2018**).
- No point in using sources which are not emitting Lyα. Focus on LAE population is therefore obvious + easy to link with selection of populations

Two complementary strategies to find distant galaxies



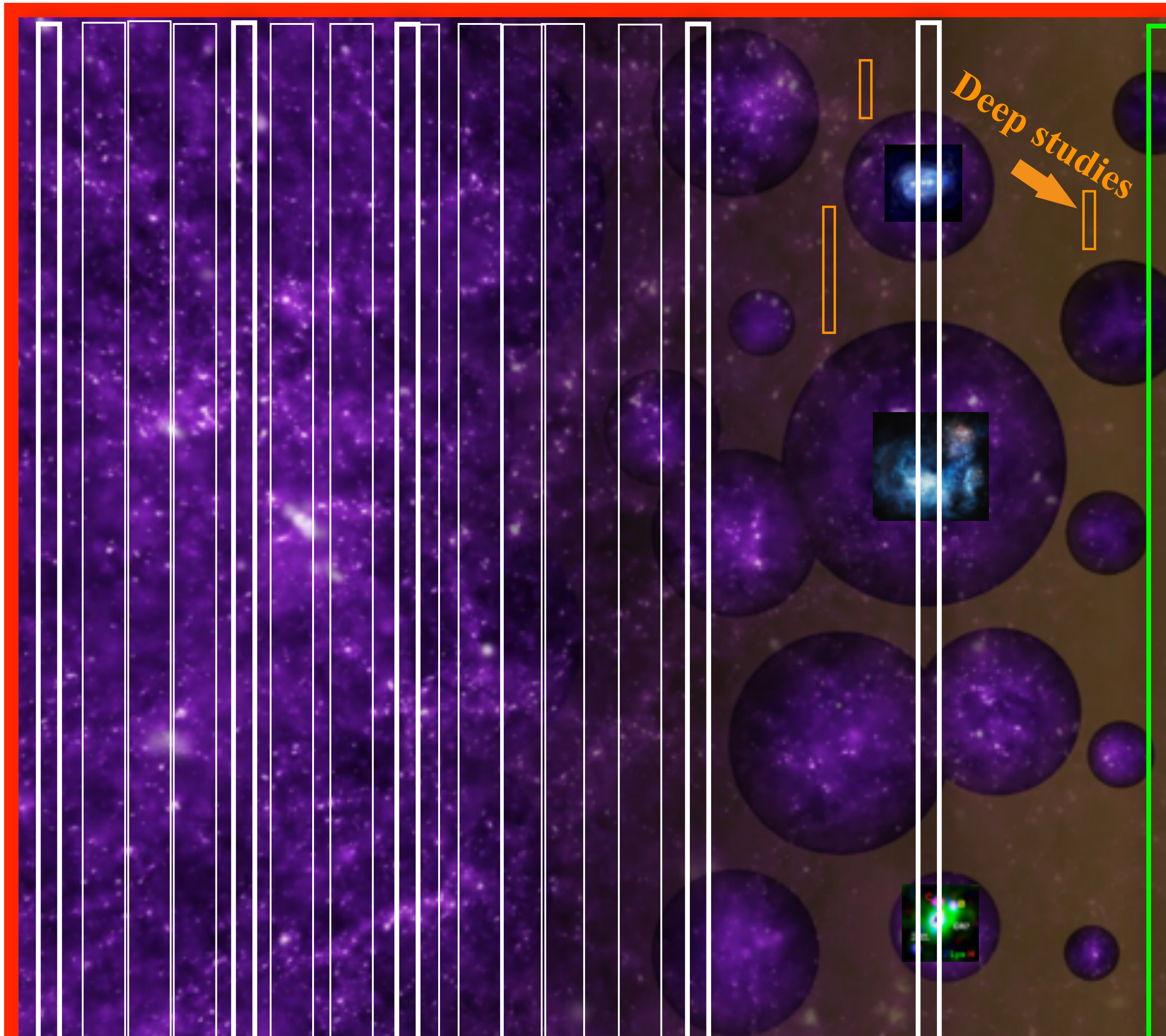
TWO COMPLEMENTARY STRATEGIES TO FIND DISTANT GALAXIES



Our approach: >10^6 Mpc^3 (~10 deg^2) Lyα slices

- **18 narrow and medium-bands** select redshifted Lyα emission from **z~2 to z~8**

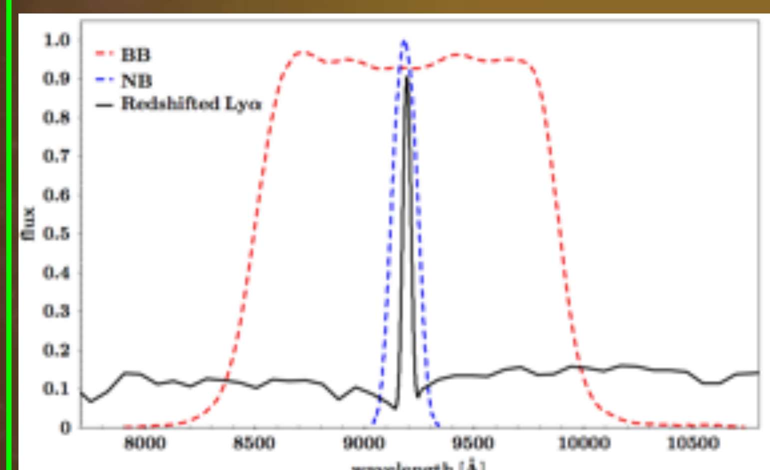
z=2.2 z=3.1 z=4.8 z=5.7 z=6.6 z=7.7



- **Fields**: COSMOS, UDS, SA22, Bootes, GOODS-N
- Down to 0.3L* in Lyα
- Galaxies as faint as J~25-26

Y-NBS (50 hrs VLT/HAWKI - PI: Sobral)

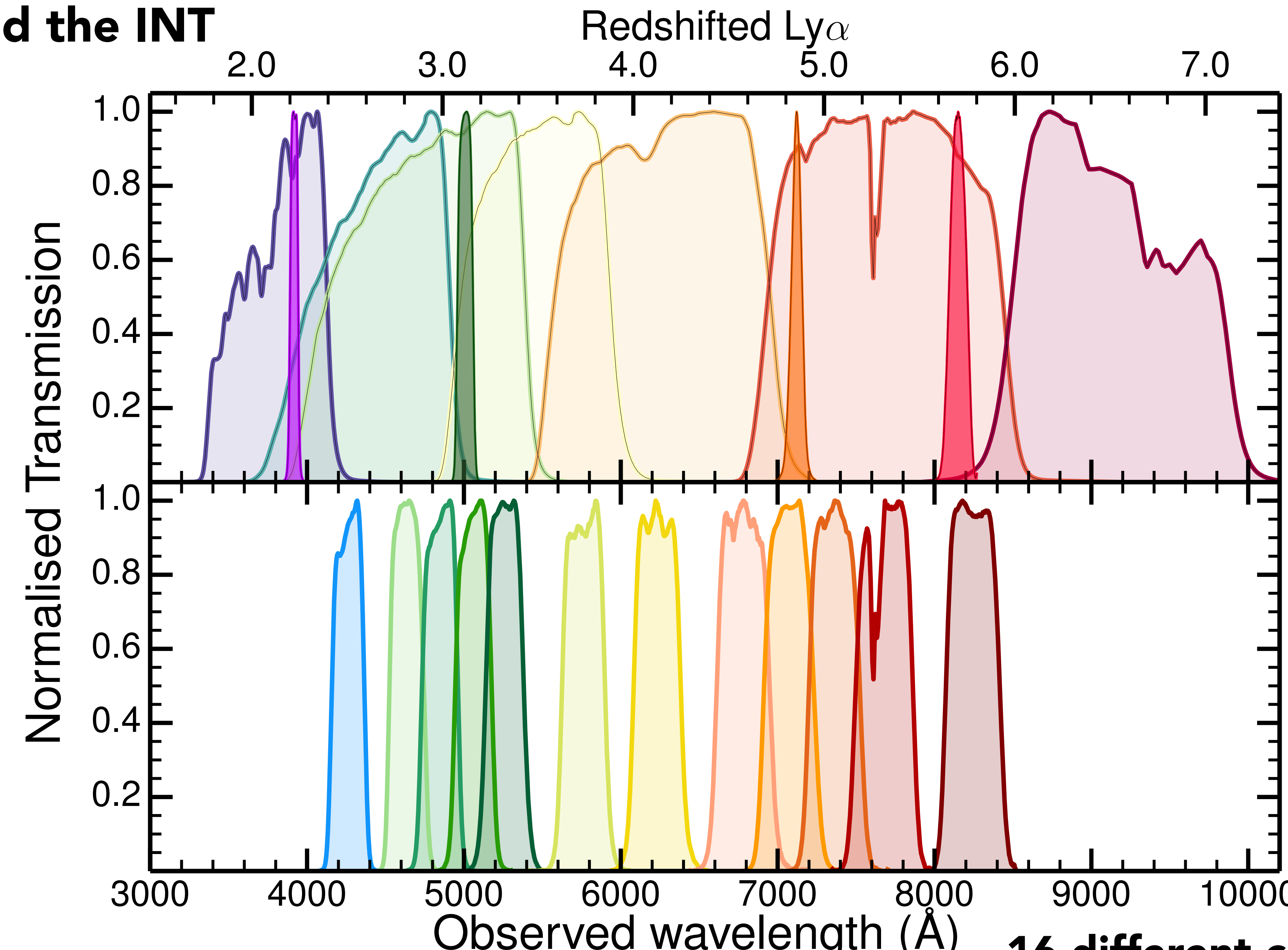
At z=2.2 complemented with all major rest-frame optical lines



Slicing COSMOS with SC4K: low-cost IFU from z~2 to z~6

16 narrow and medium filters on Subaru and the INT

Sobral et al. 2018a



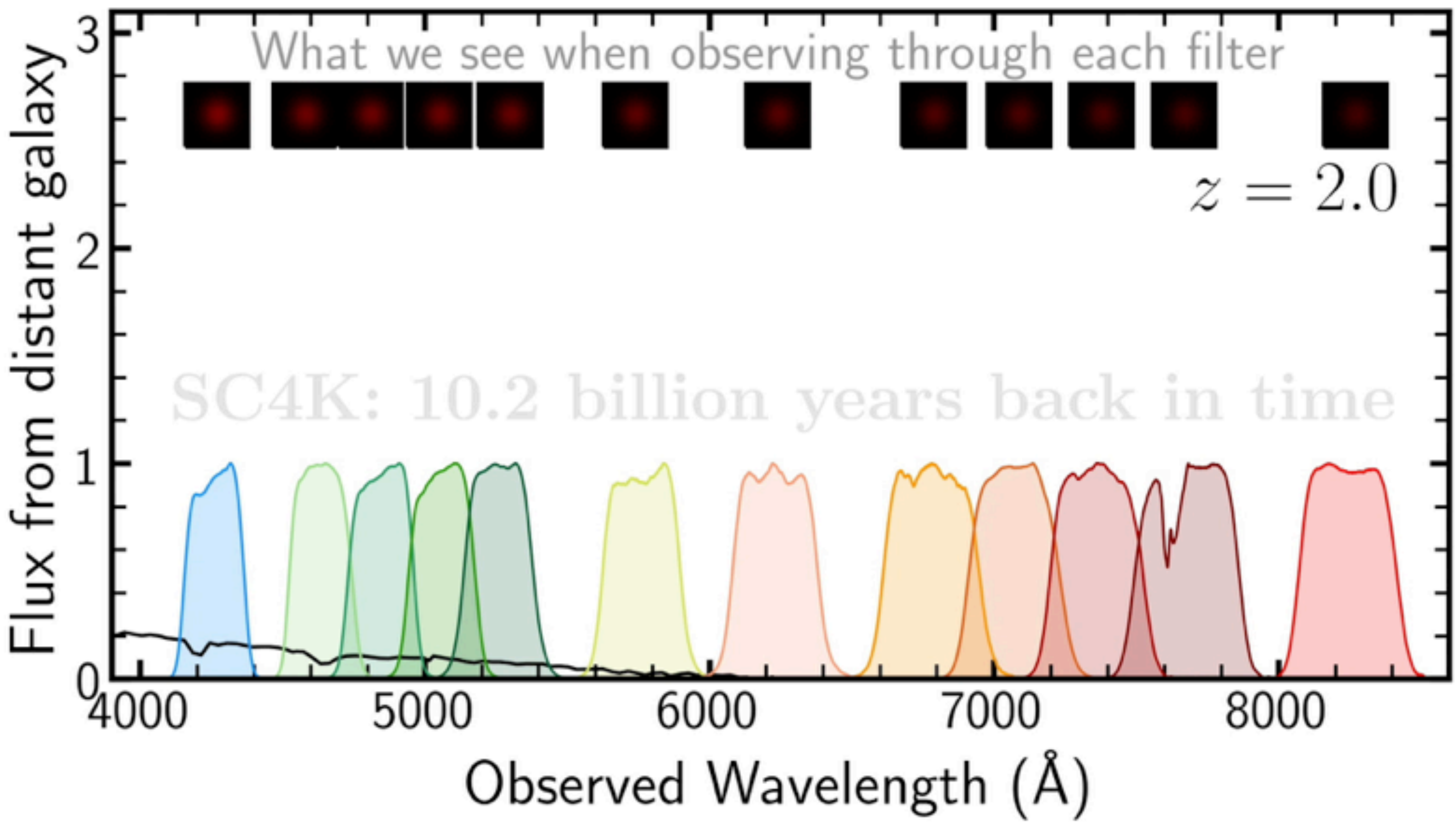
16 different catalogues

Slicing COSMOS with SC4K: low-cost IFU from z~2 to z~6

16 narrow and medium filters on Subaru and the INT

Sobral et al. 2018a

16 different catalogues



Slicing COSMOS with SC4K: low-cost IFU from z~2 to z~6

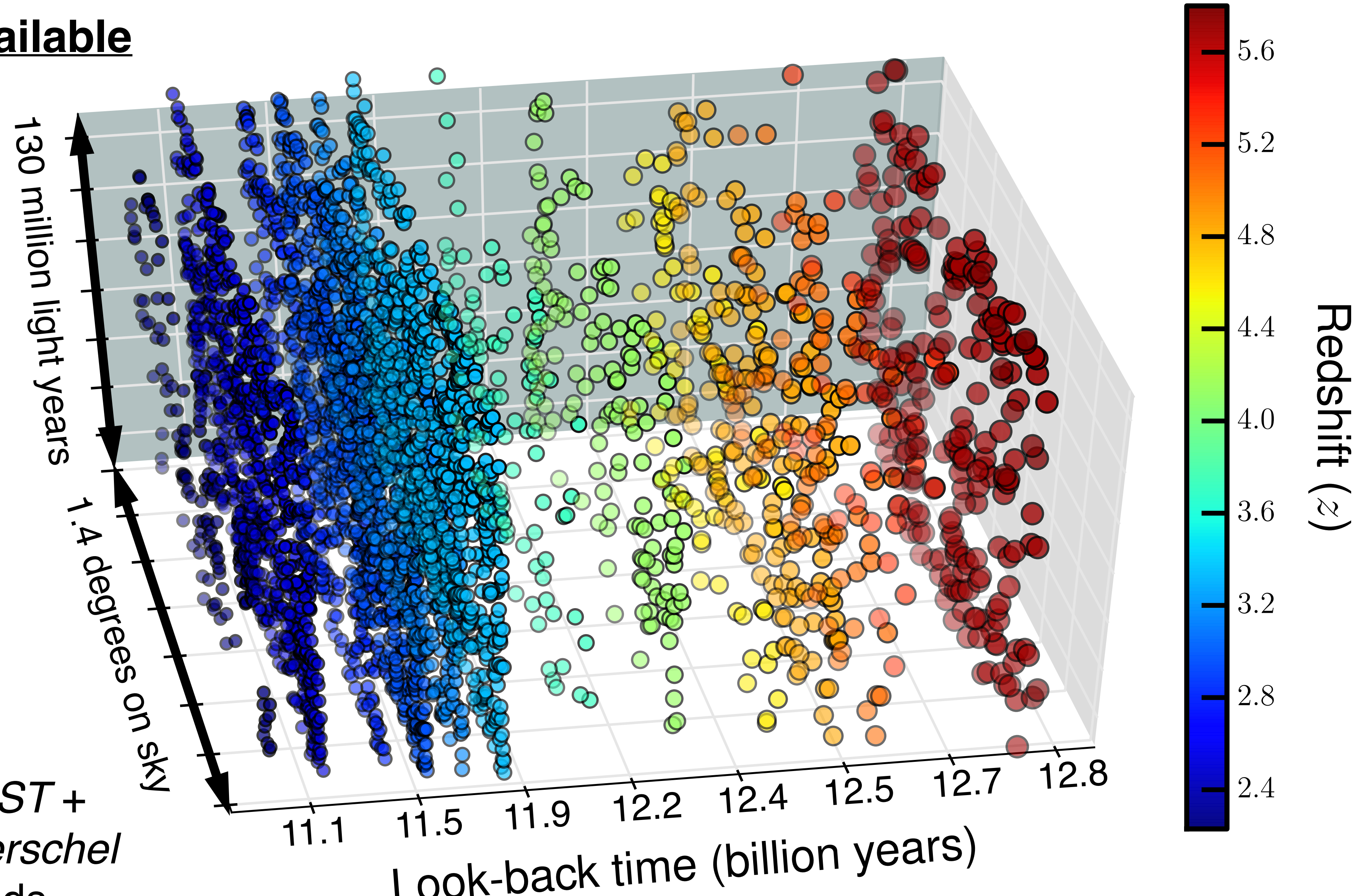
16 narrow/medium bands => **~4000 Lyα emitters:** 2<z<6 in the **COSMOS** field

Complementary to MUSE: 2 deg²

Sobral+18a, MNRAS, 476, 4725

Publicly available

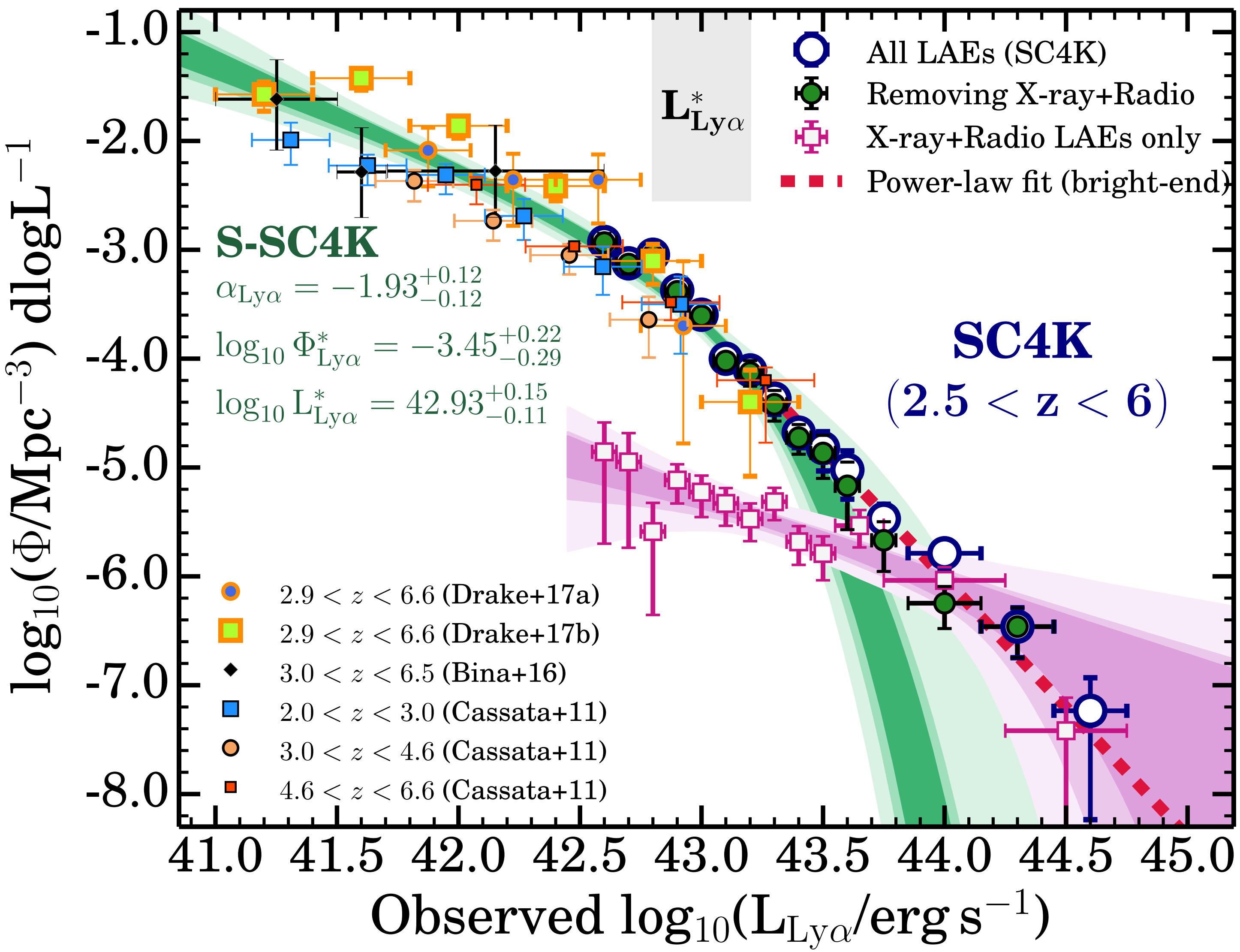
(inc. IPAC)



All having *HST* + *Chandra* + *Herschel* + ~30 bands

The global Lyα luminosity function at z~2-6: consensus

<u>Steep</u> faint-end slope: α~ -2. **Sobral+18a, MNRAS, 476, 4725**



SC4K co-moving volume: ~**10^8 Mpc^3**

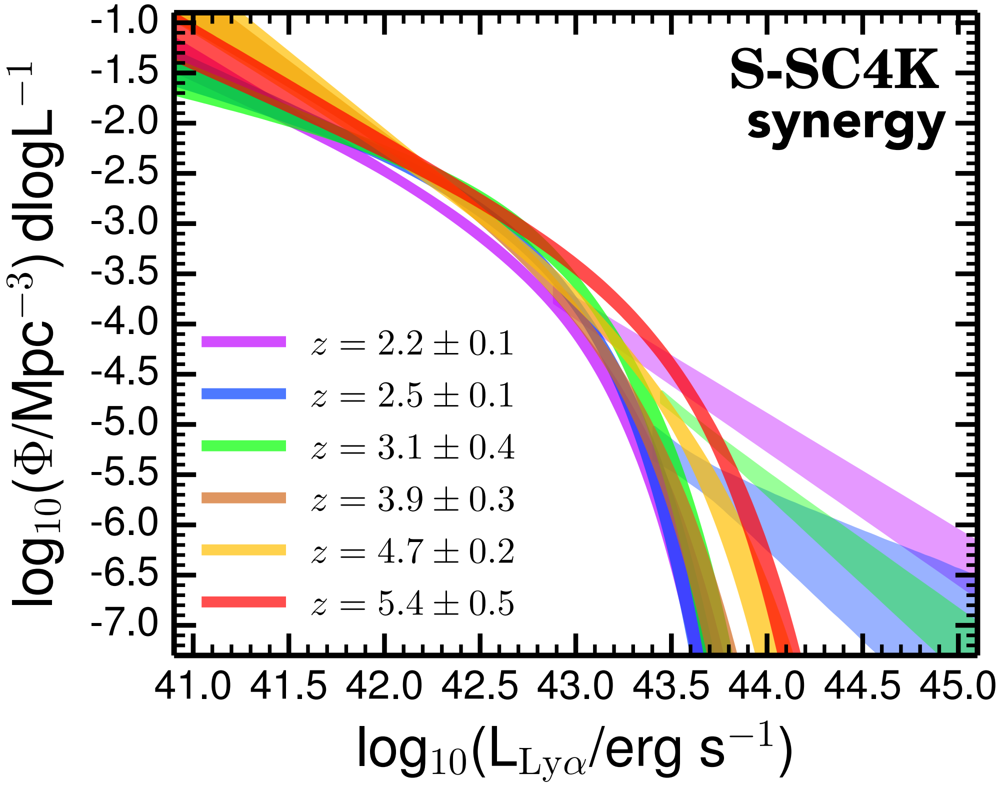
Unique synergy:

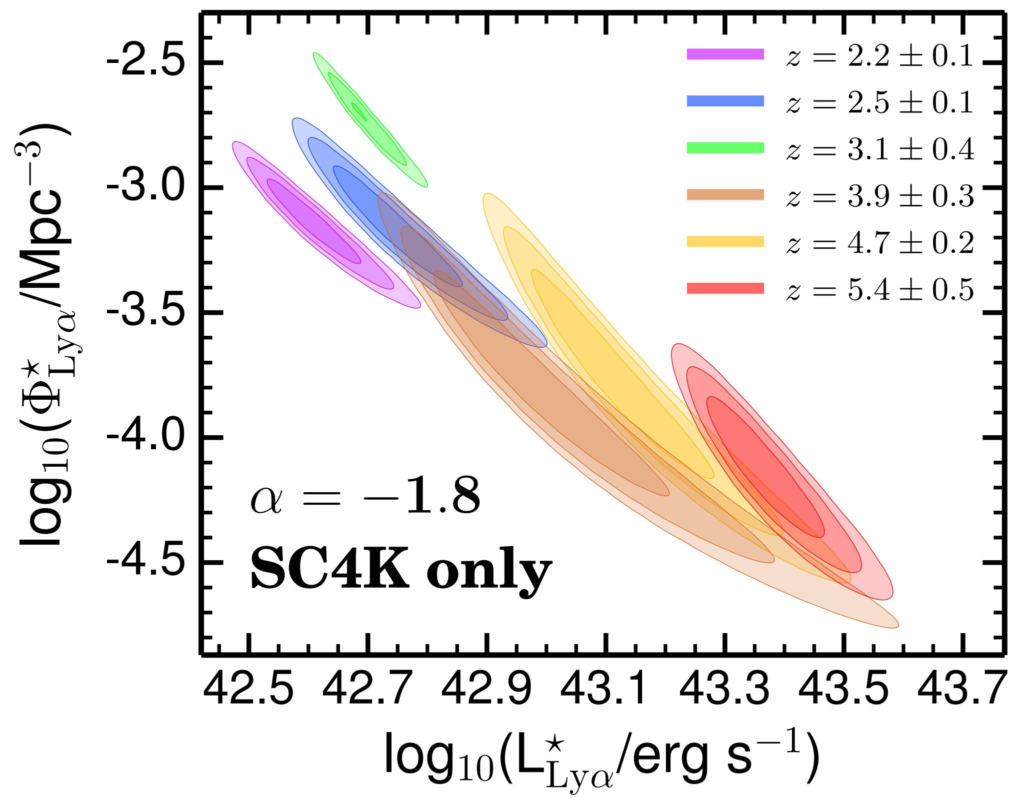
MUSE ultra-deep at low luminosities + SC4K: 4 orders of magnitude!

See also: **Drake+2017a,b;** Dressler+2015; **Santos, DS & JM 2016; Konno+2016.**

Evolution of the Lyα luminosity function z~2-6: census

See full redshift by redshift evolution + literature comparison in
Sobral+18a, MNRAS, 476, 4725





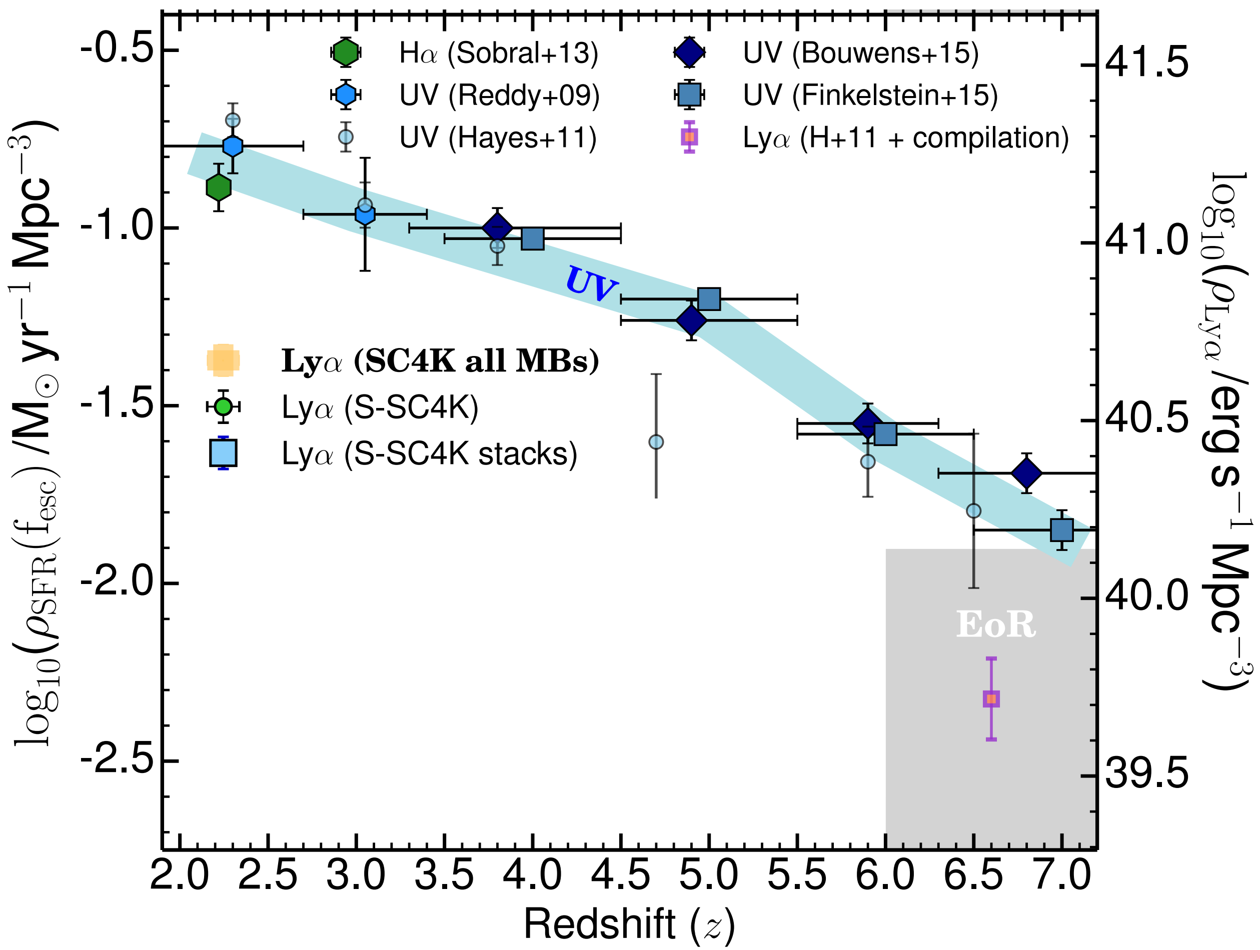
Steep faint-end slope: α~ -1.7 to **α~ -2.3**
$L^*_{Ly\alpha}$ rises by a **factor of ~5** from z~2 to z~6
$\Phi^*_{Ly\alpha}$ declines by a **factor of ~7** from z~2 to z~6

See full **S-SC4K synergy compilation** in Sobral+18a; arXiv: 1712.04451

UV luminosity density drops quickly with redshift

- **UV luminosity density declines: what about Lyα?**

Sobral+18a, MNRAS, 476, 4725

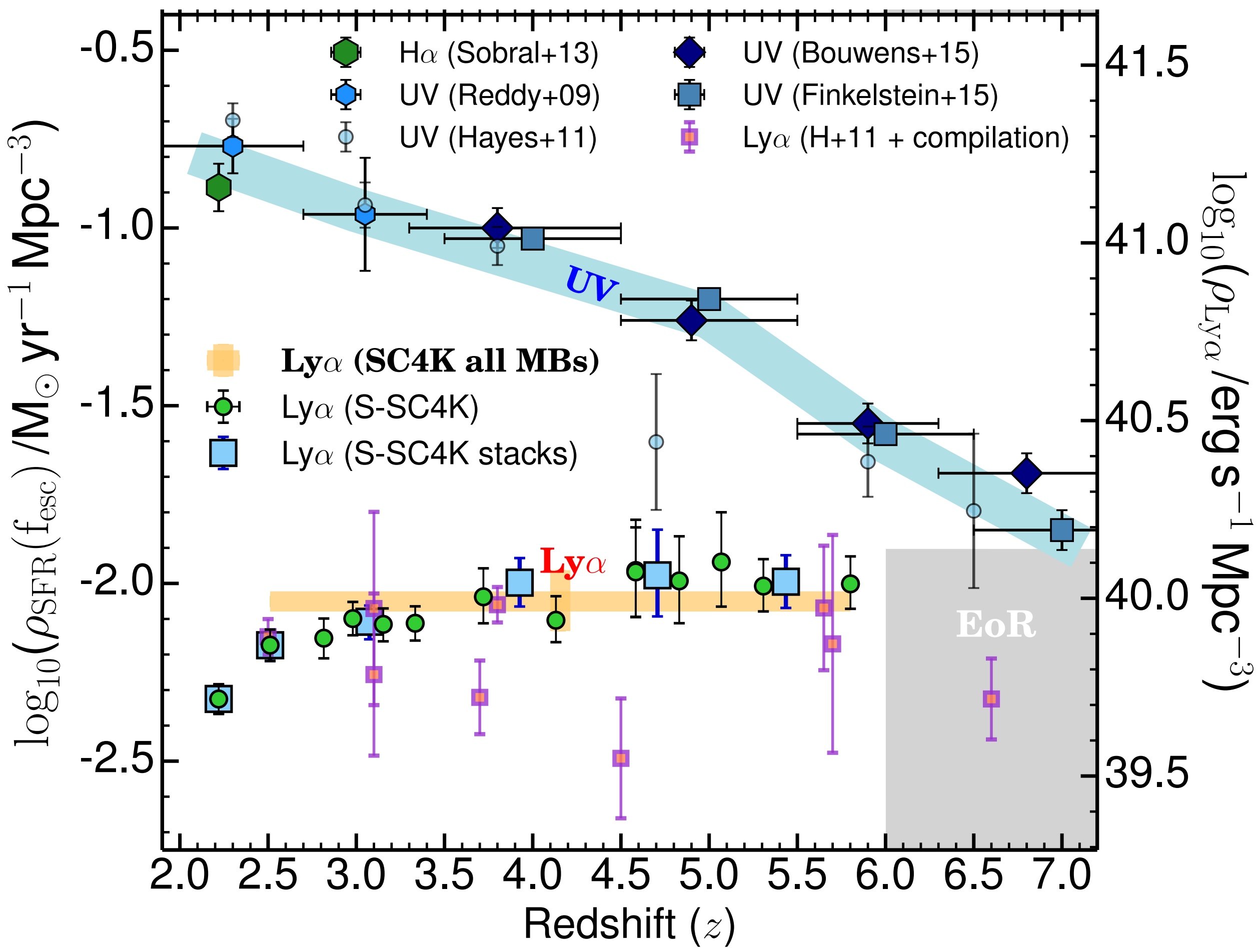


<u>**See also**</u>: Hayes et al. 2011; Konno+2016,2018; Stark+2017; Zheng+2017; Santos+2016; Matthee+2015, 2017a

More Lyman-α per UV luminosity density at higher redshift

- Rising Lyα luminosity density **while UV luminosity density declines.**
- Younger, less dusty galaxies at higher-z?

Sobral+18a, MNRAS, 476, 4725



Does Lyα f_{esc} increase (roughly same production but more escape)**?**

Does ξion increase (more production of LyC/UV)**?**

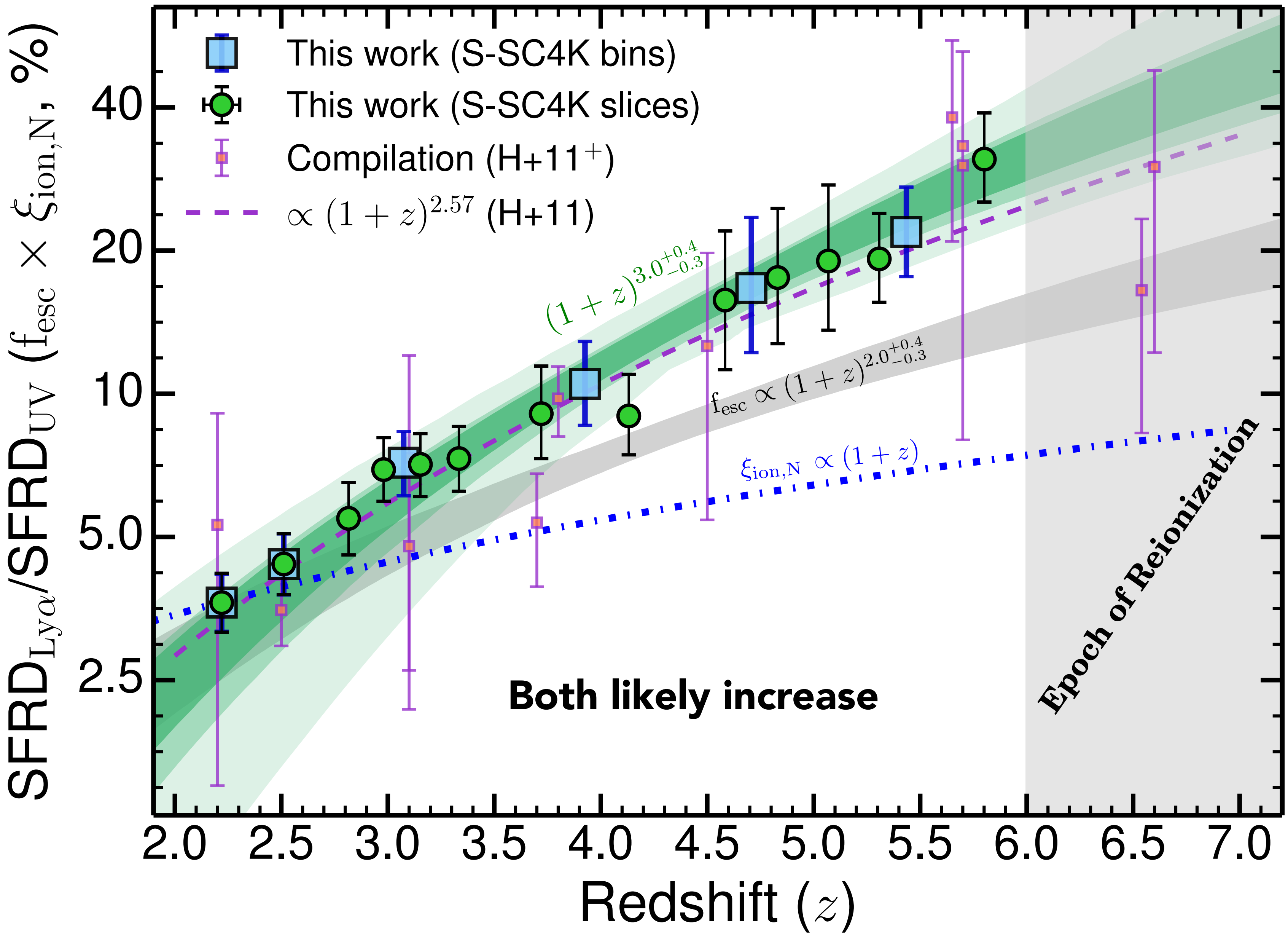
Do both increase?

See also: Hayes et al. 2011; Konno+2016,2018; Stark+2017; Zheng+2017; Santos+2016; Matthee+2015, 2017a

More Lyα/UV at higher redshift: what does it mean physically?

LyC/UV production increases by a **factor of ~2**
Cosmic Lyα f_{esc} increases by a **factor of ~4**

See full details in:
Sobral+18a, MNRAS, 476, 4725



High-z galaxies have **high EWs, typical of LAEs**

Imply very high ionisation parameters, low metallicities + “extreme” stellar populations

What does that mean for **galaxies as a whole**?

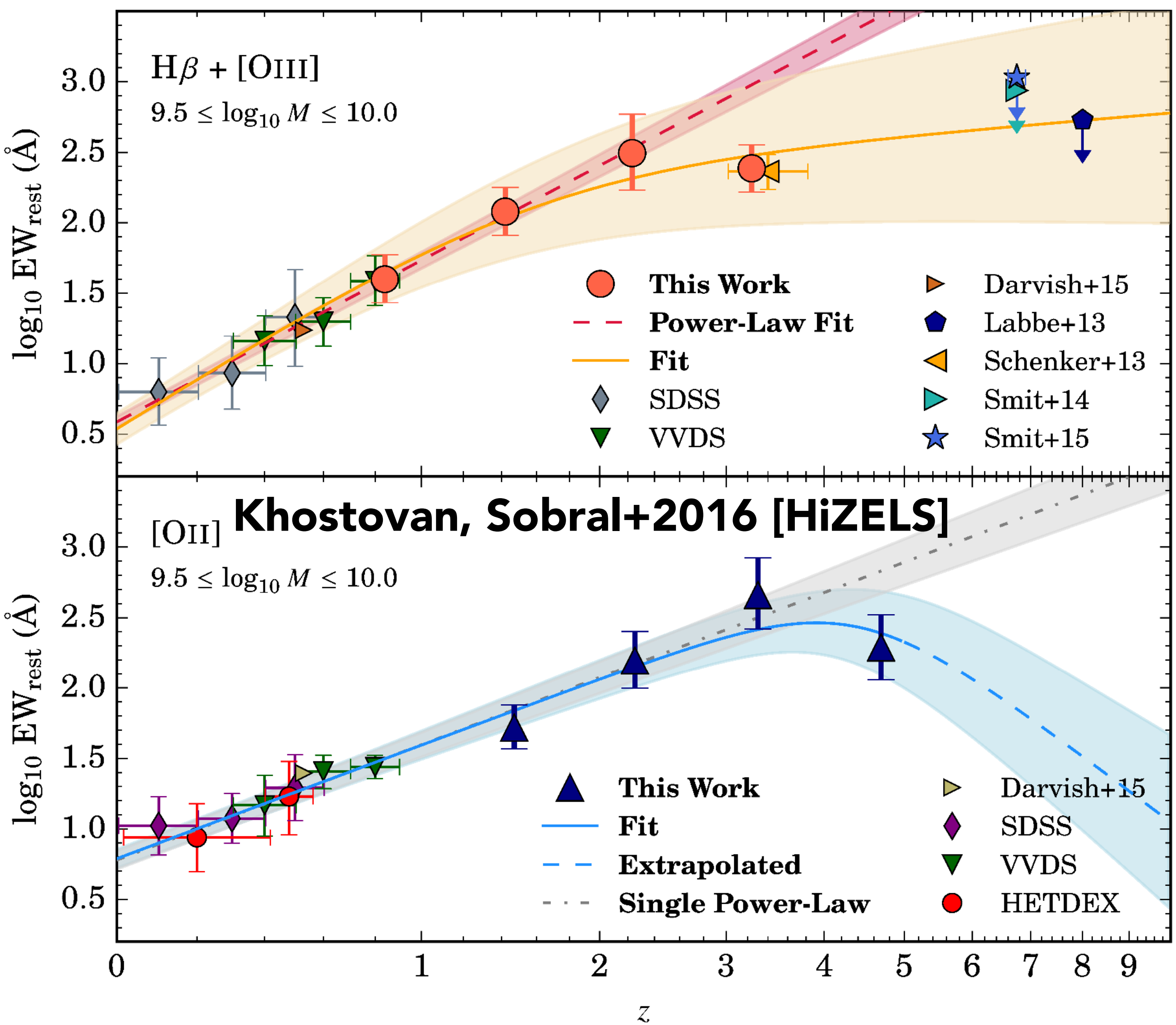
What does that mean for **LAEs**?

Khostovan, Sobral+2016 [HiZELS]

See also: Fumagalli+12; Sobral+14; Smit+14; Marmol-Queralto+15; Nakajima+16,18; Holden+16; de Barros+16; Stark+16;

High-z galaxies have **high EWs, typical of LAEs**

Imply very <u>high ionisation parameters</u>, <u>low metallicities</u> + "extreme" stellar populations



At low redshift the analogues (blueberries, green-peas etc) are super-rare (~10^{-8} Mpc^{-3}): Izotov+2016; Borthakur+; Schaerer+16; Yang+17,18

<u>At high redshift, most galaxies are LAE-like</u>

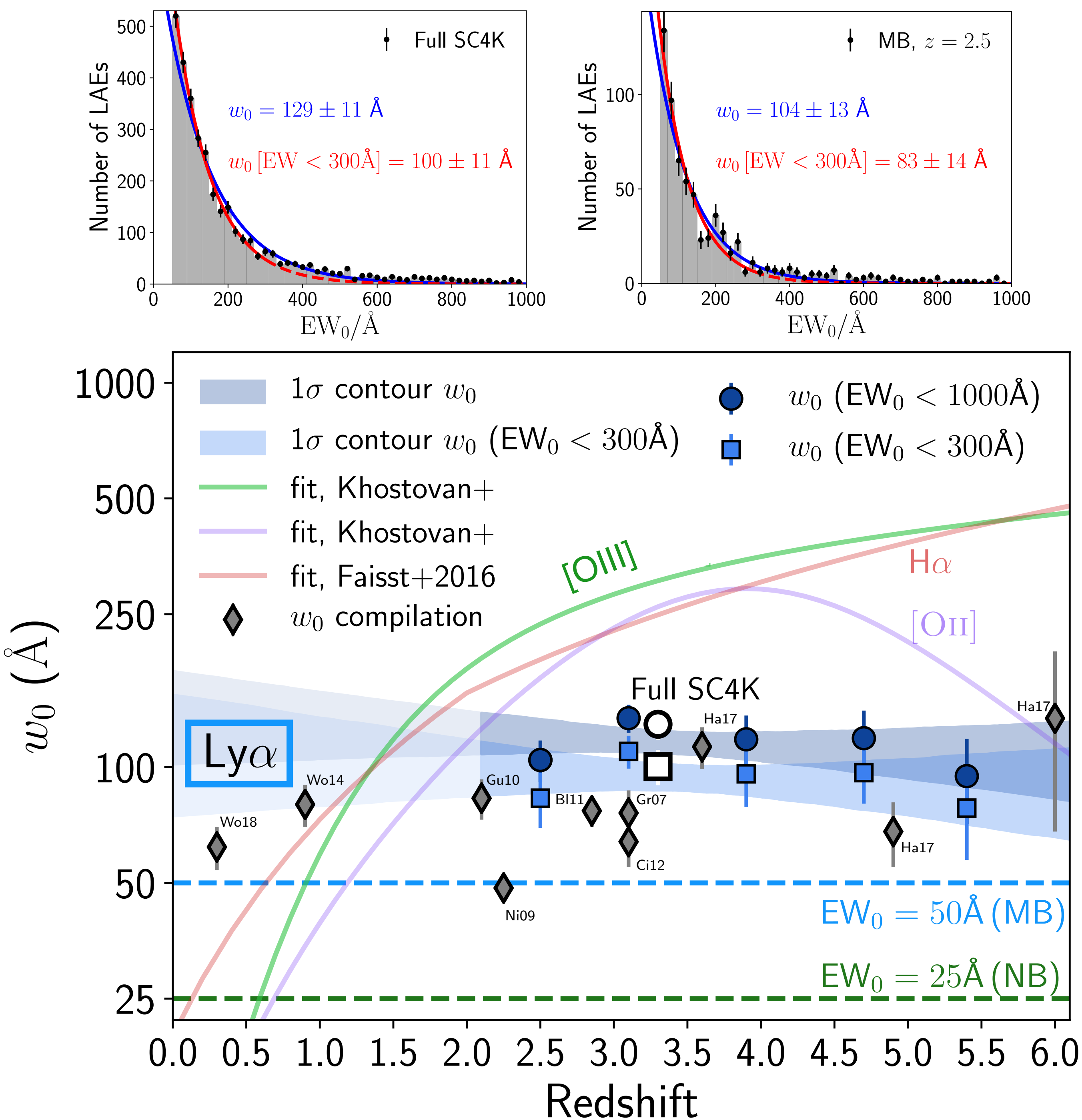
What are their (stellar) metallicities/abundances?

See also: Fumagalli+12; Sobral+14; Smit+14; Marmol-Queralto+15; Nakajima+16,18; Holden+16; de Barros+16; Stark+16;

EW$_0$ of Lyα selected ~constant across redshift

Santos, Sobral et al. in prep.

$$f_{esc,Ly\alpha} = 0.0048^{+0.0007}_{-0.0007}\, EW_0 \pm 0.05$$



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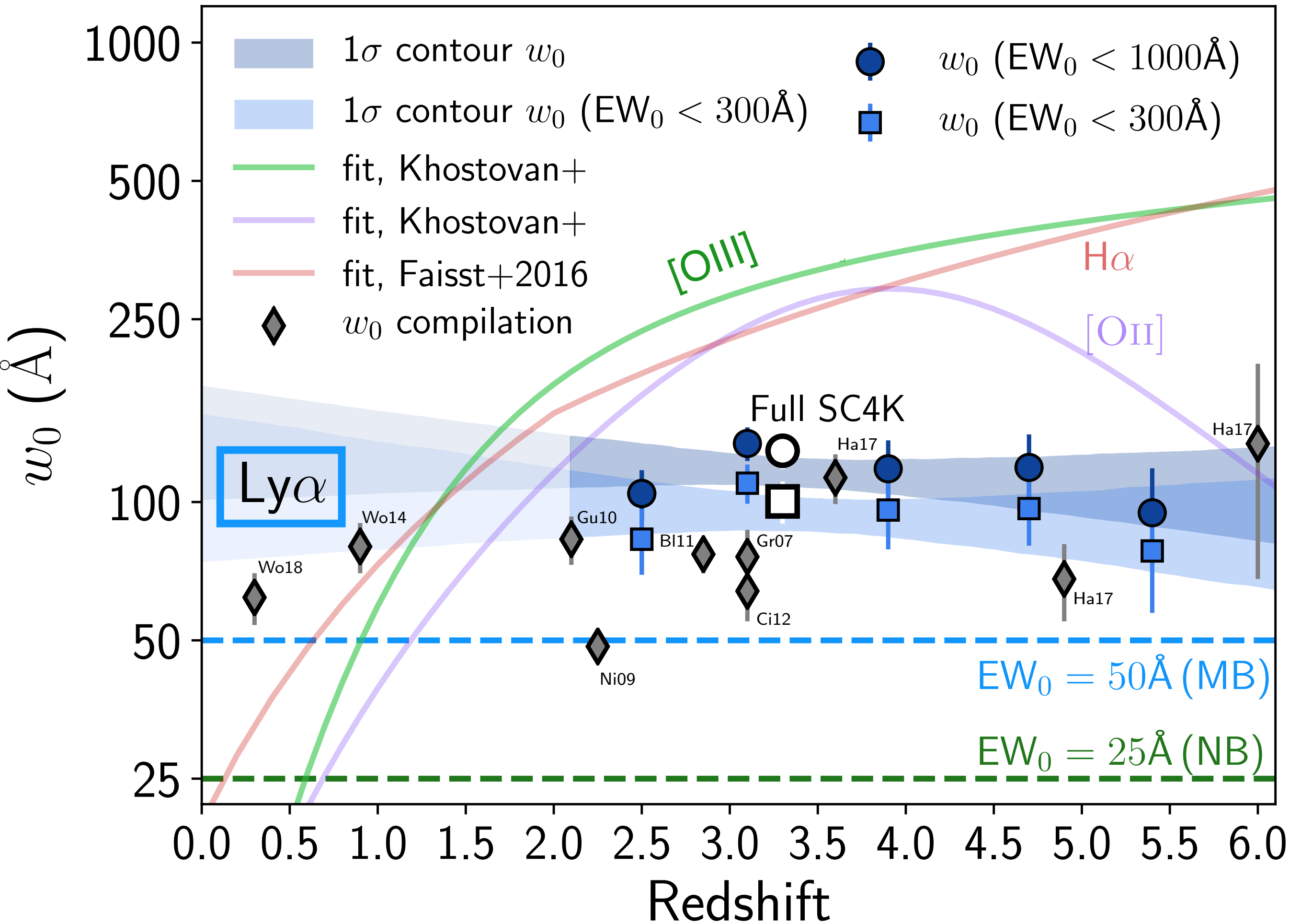
Santos, Sobral et al. in prep.



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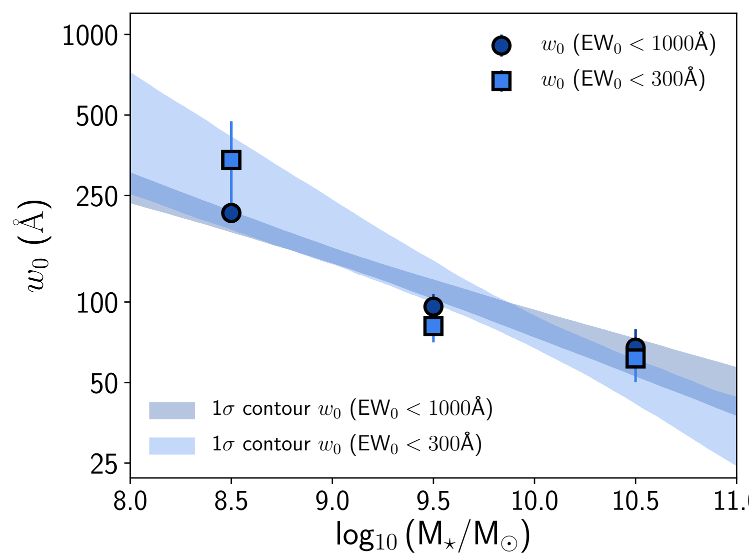
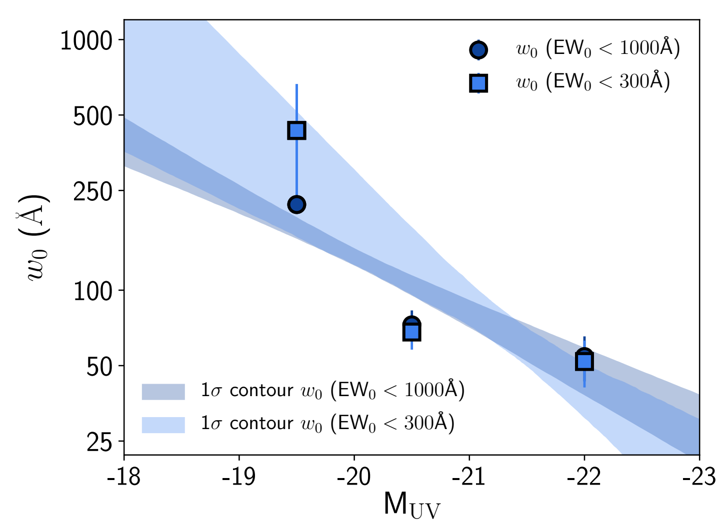
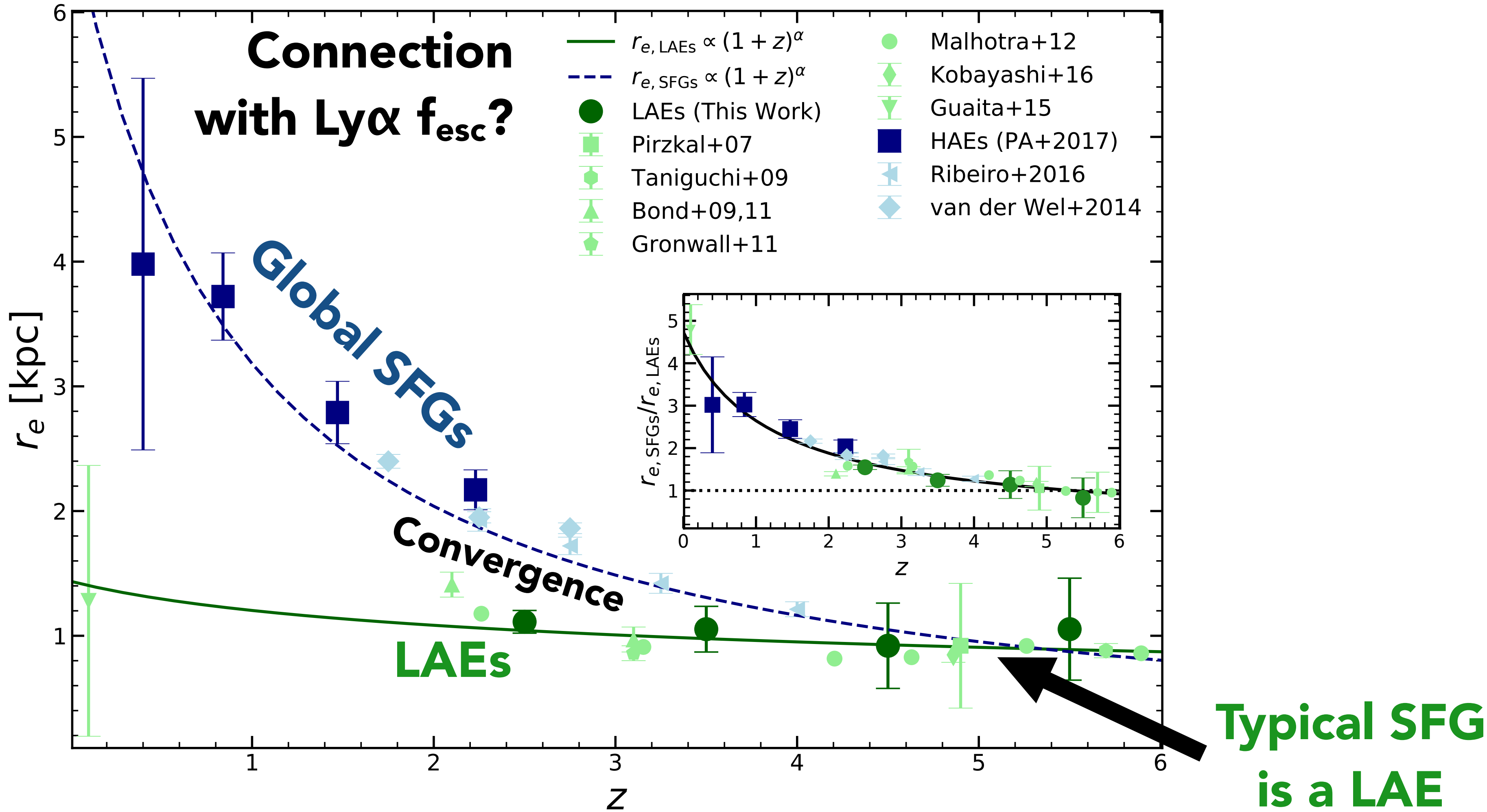




Sizes of SFGs converge to the LAE-like at high-z: 1kpc

On the UV compactness and morphologies of typical Lyman-α emitters from $z \sim 2$ to $z \sim 6$

Paulino-Afonso, Sobral+2018a, MNRAS, 476, 5479

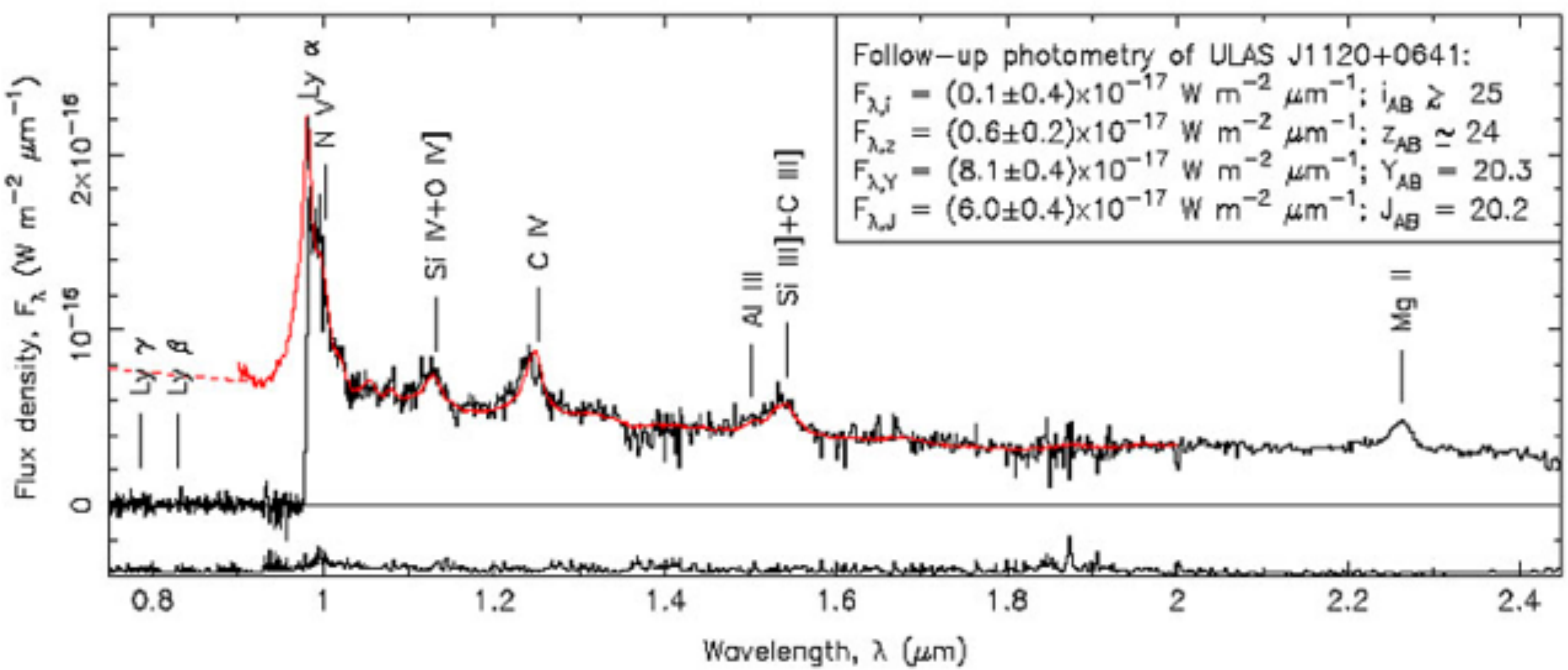


Lyα emitters always small/compact across time (~1 kpc)

Not just star formation of course: AGN as well!

- Quasars are some of the brightest Lyα (and line-) emitters known - searches for Lyα emitters can therefore find them - let's not discriminate

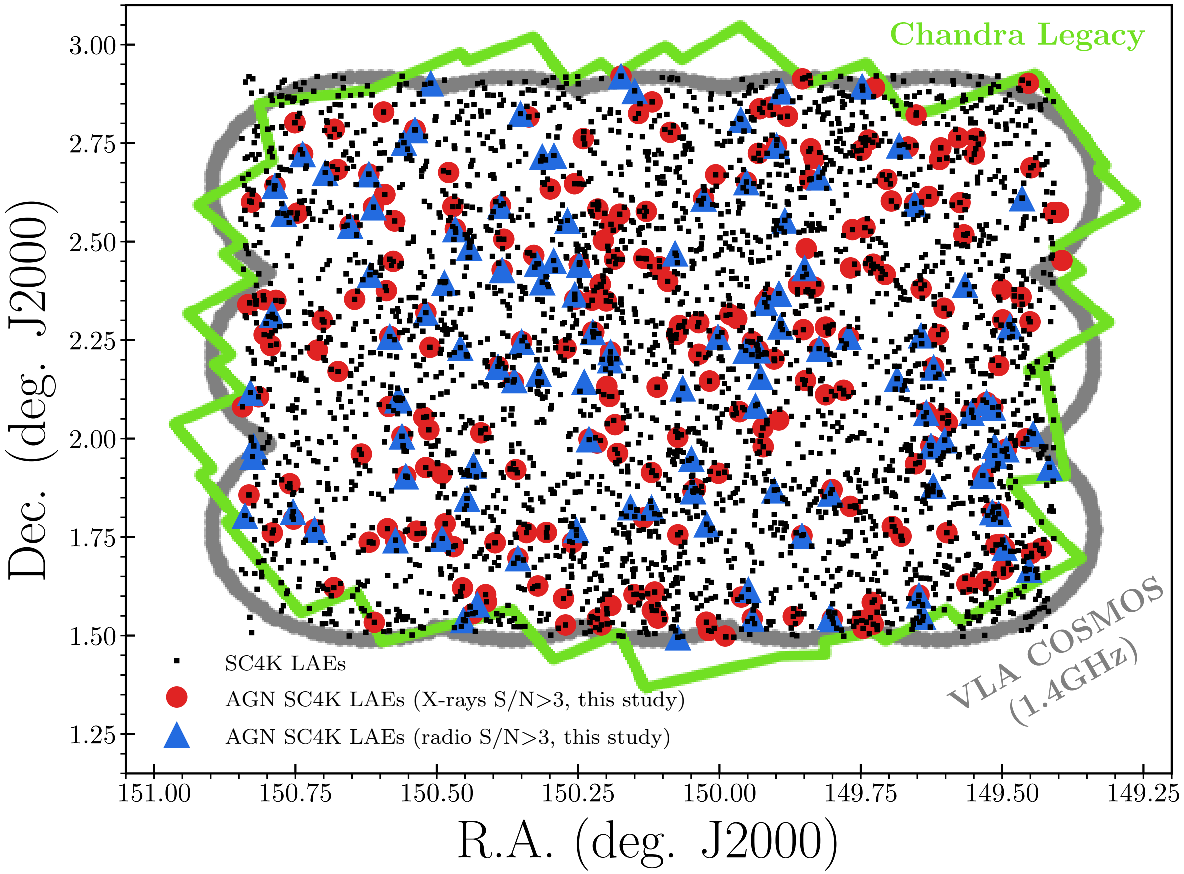
z = 7.085; Mortlock et al. 2011



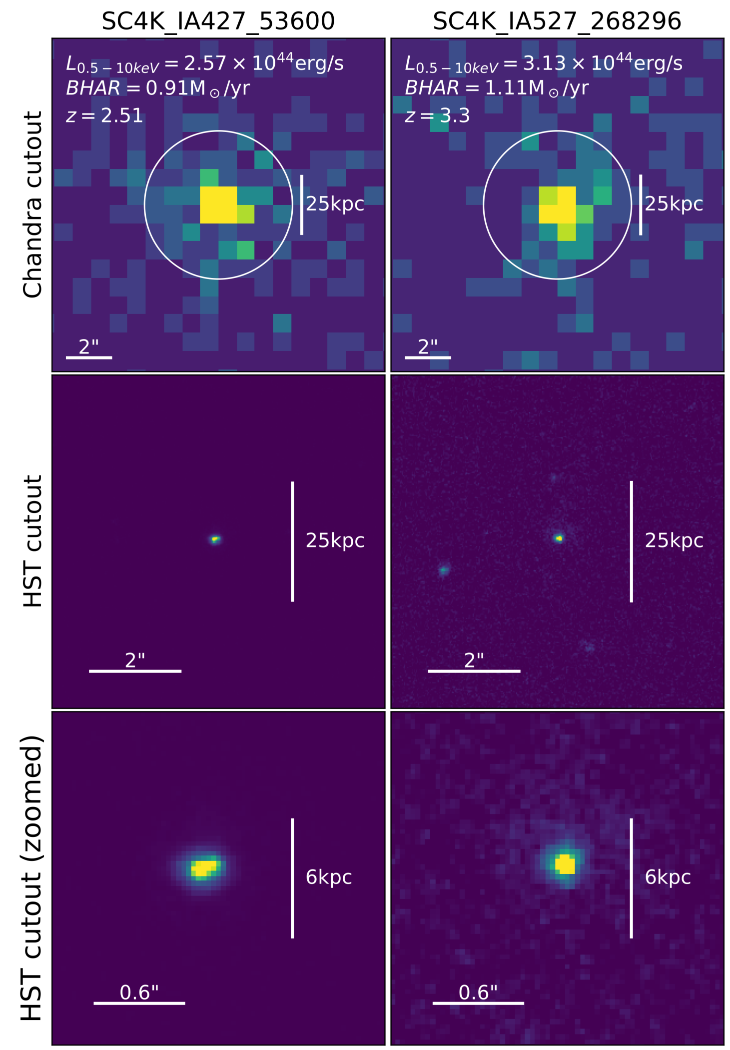
See also: Venemans+2013; Cantalupo+2014; Borisova+2016; Bañados+2016, 2018

Identifying AGN among Lyα emitters in SC4K/COSMOS

COSMOS: *Chandra* + VLA data



Calhau, Sobral et al. in prep.



Only ~2-5% of Lyα emitters detected by *Chandra* in X-rays <u>254 sources</u>.

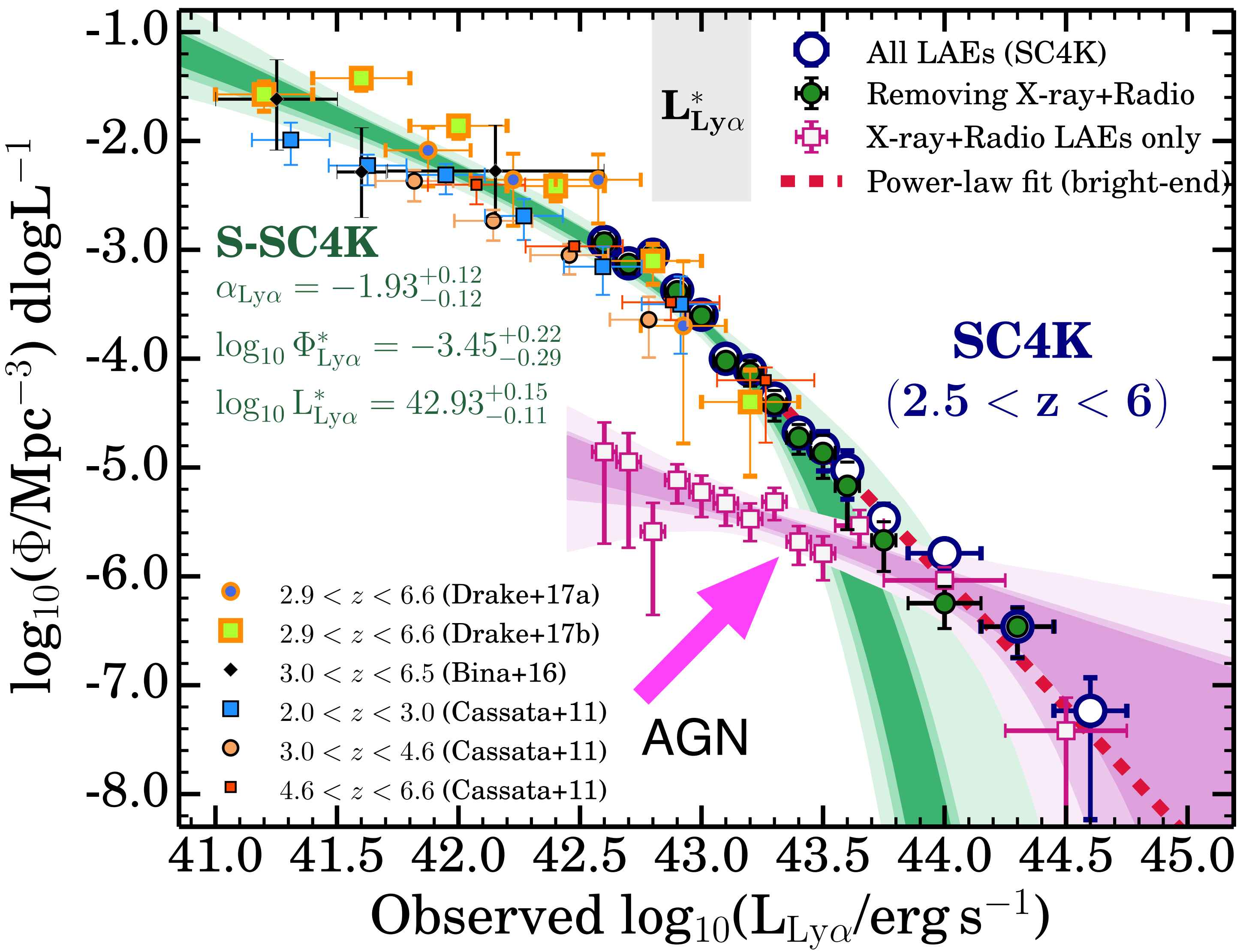
Detected are luminous, rapidly accreting SMBHs

see also Cowie et al. (2010); Wold et al. (2014); Matthee et al. (2017)

The global Lyα luminosity function at z~2-6: consensus

Bright-end falls like a ~power-law (AGN), or shallower exponential

Sobral+18a, MNRAS, 476, 4725



AGN luminosity function: tracing proto-clusters

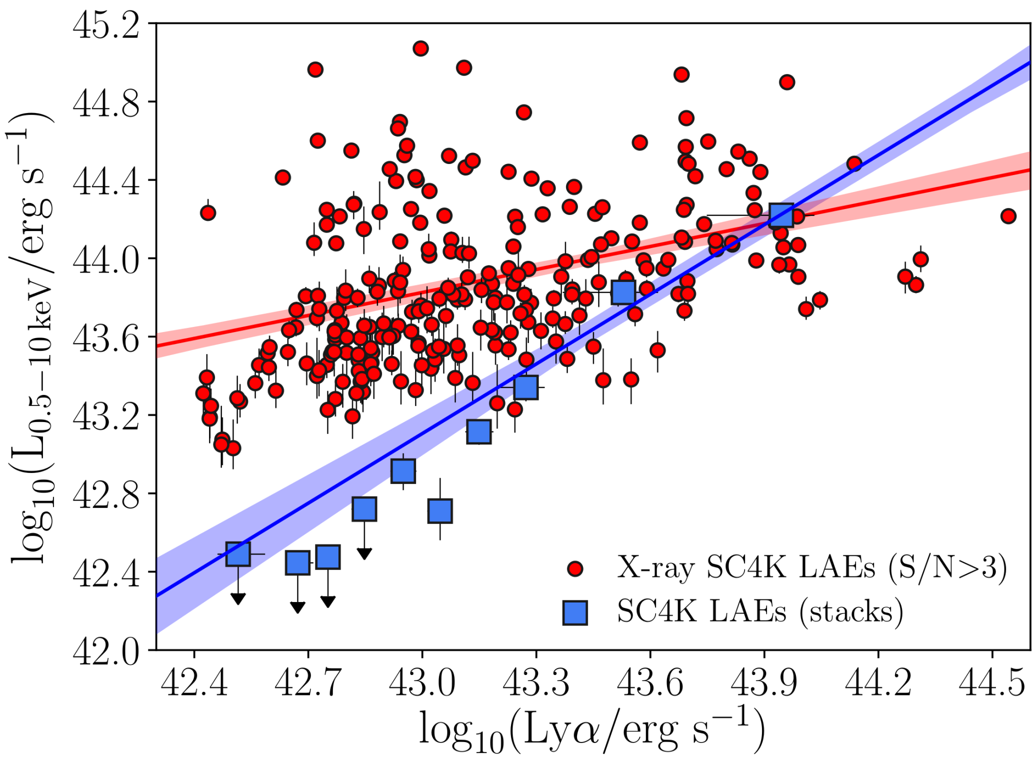
SC4K co-moving volume: ~**10^8 Mpc^3**

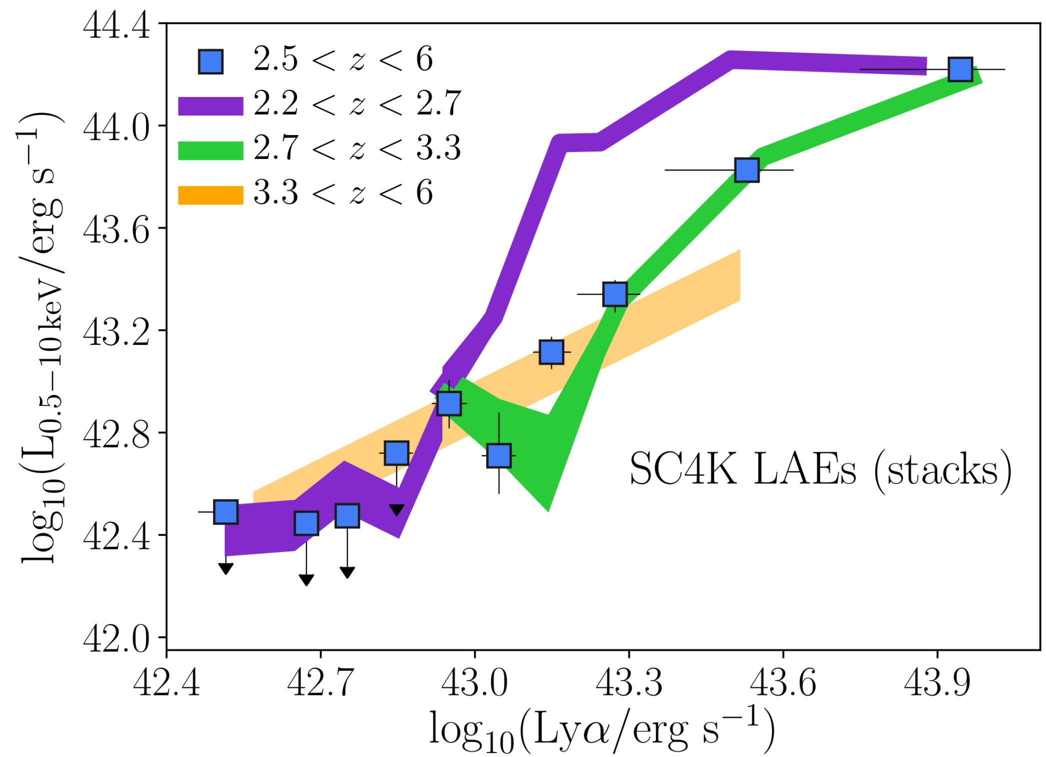
See also: **Drake+2017a,b;** Dressler+2015**; Santos, DS & JM 2016; Konno+2016.**

Lyα luminosity tracing accretion rates/rapid SMBH growth

Above a certain Lyα luminosity, Lyα seems to just trace black hole accretion rate: Lyα-L_X correlation. Lyα becomes a super-massive black hole accretion rate estimator

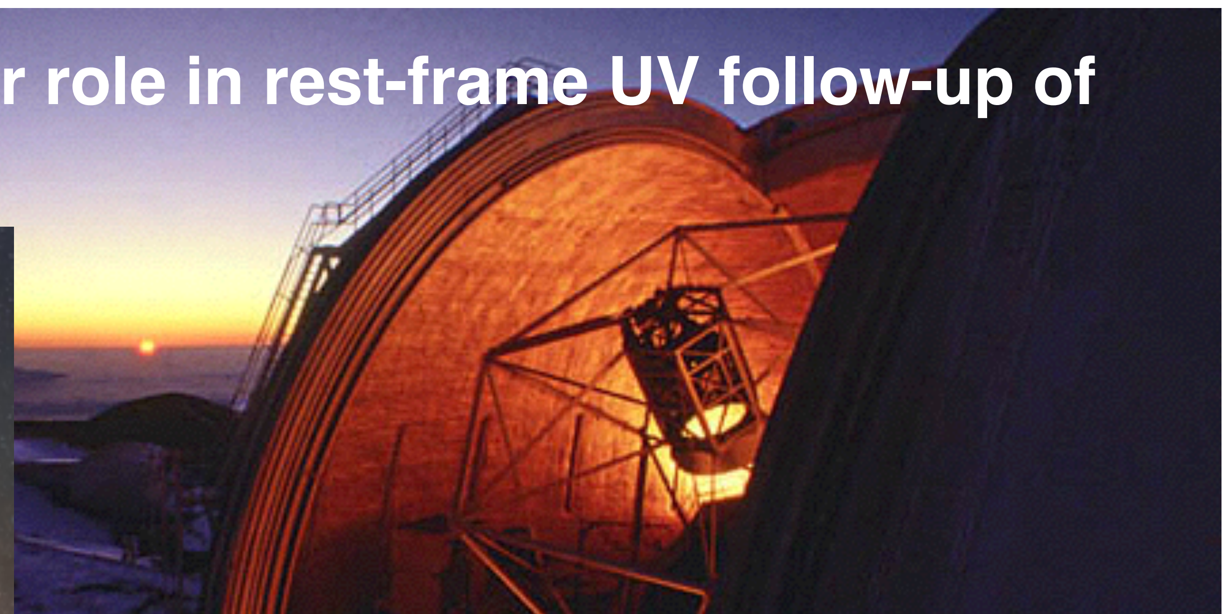
Calhau, Sobral et al. 2019





Are we missing AGN with current deep X-ray data?

- Deep spectroscopy allows to see much lower accretion rates from likely lower mass SMBHs
- Do fainter Lyα emitters also contain a SMBH, but just below the detection limit?
- Spectroscopic follow-up of luminous LAEs: **Keck, VLT, WHT**

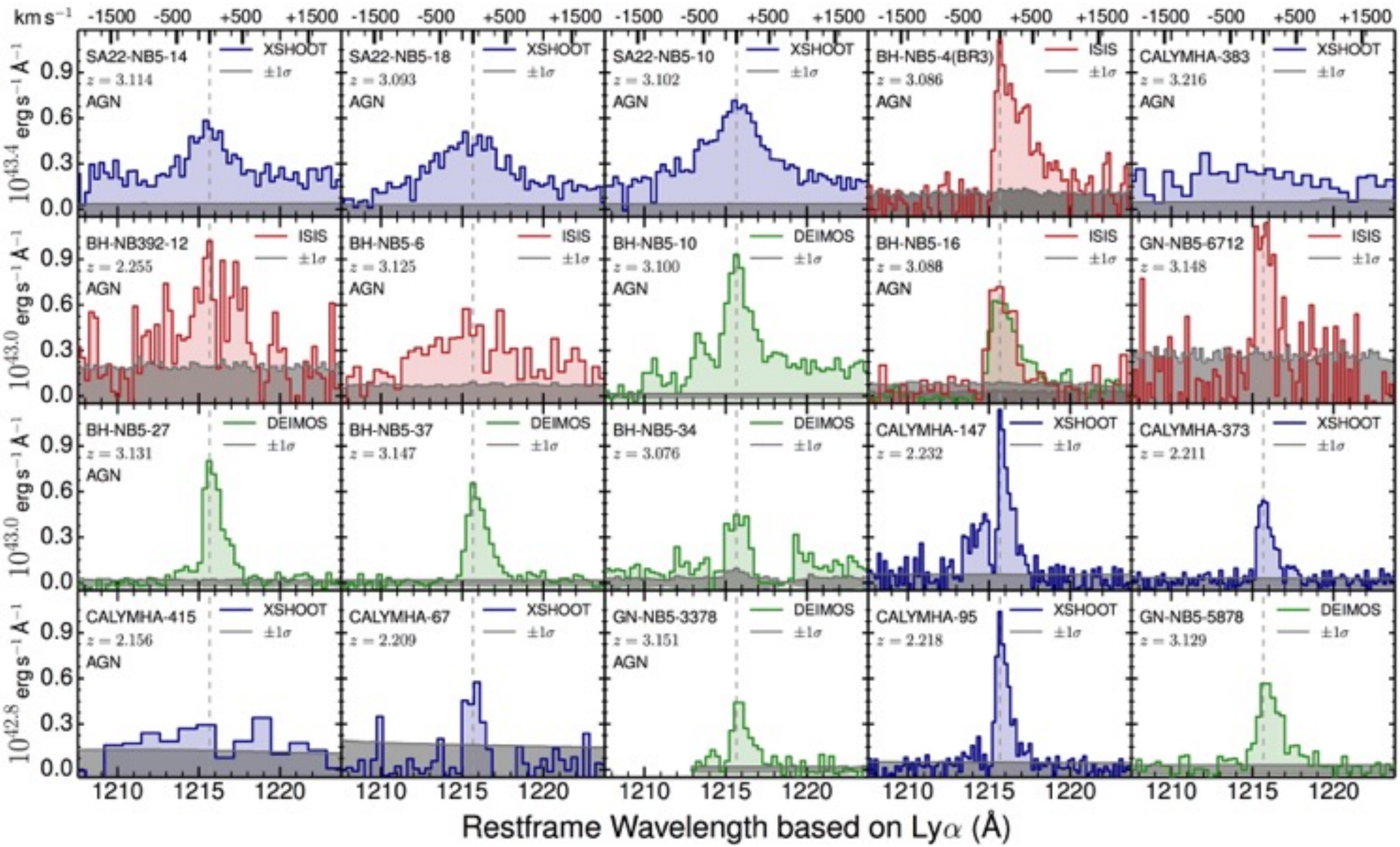


Sobral et al. 2018b, MNRAS, 477, 2817

Lyα FWHM: from very broad to narrow with decrease

Decreasing Lya luminosity →

Sobral et al. 2018b



Most AGN LAEs are not detected in X-rays (but variable data quality!)

Identifying AGN vs metallicity effects: rest-UV

Photo-ionisation models over a wide range of params (published with):

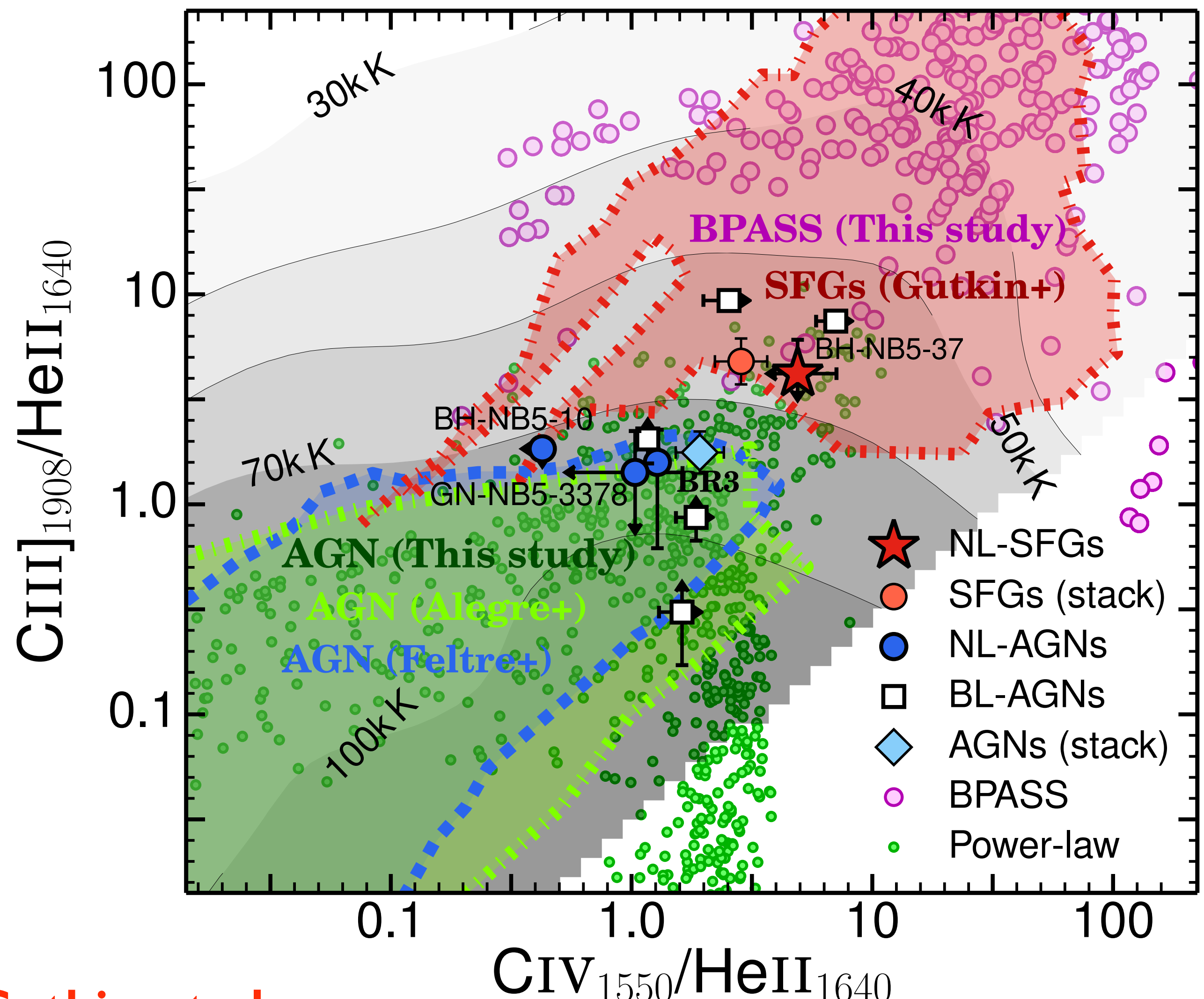
Sobral et al. 2018b, MNRAS, 477, 2817

Sobral et al. 2019a, MNRAS, 482, 2422

Identifying AGN activity in LAEs with high ionisation rest-frame UV lines

Most do not show detections in X-rays

Sobral et al. 2018b

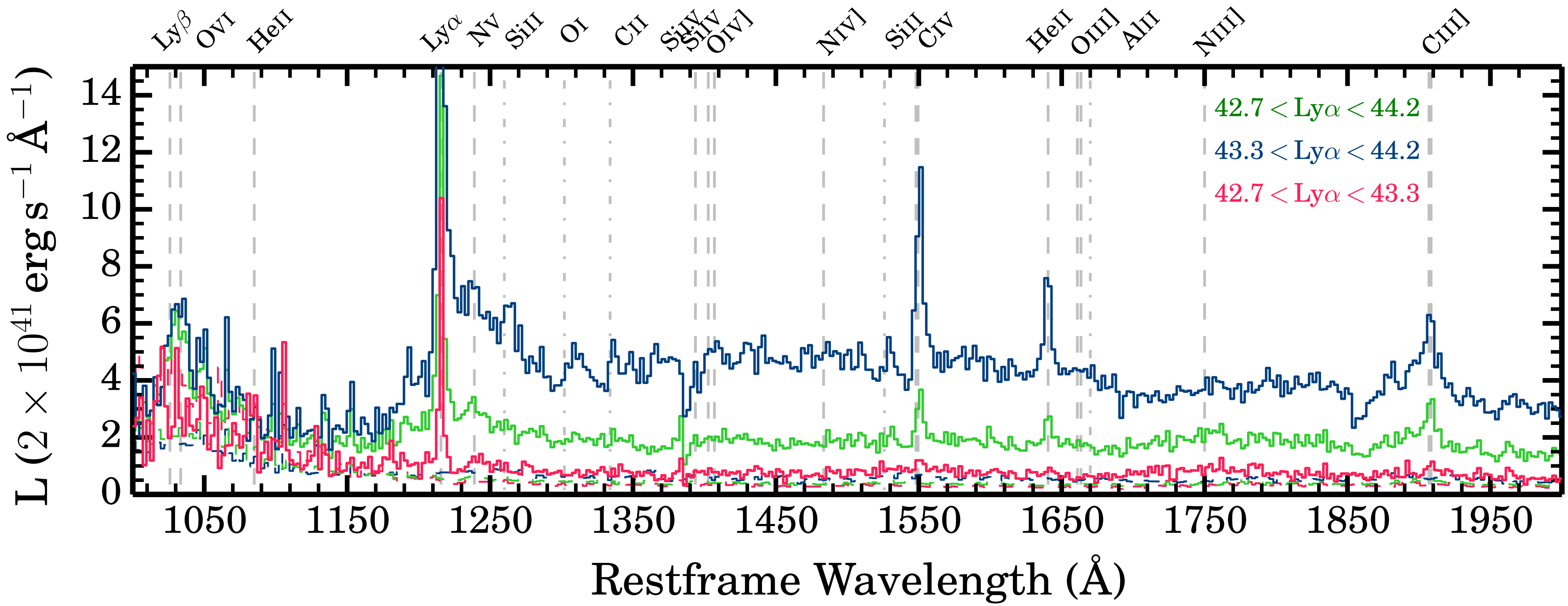


See also: Feltre et al. & Gutkin et al.

ISM of Lyα shifts from metal-poor SF to metal-rich AGN

CLOUDY photo-ionisation modelling

Sobral et al. 2018b



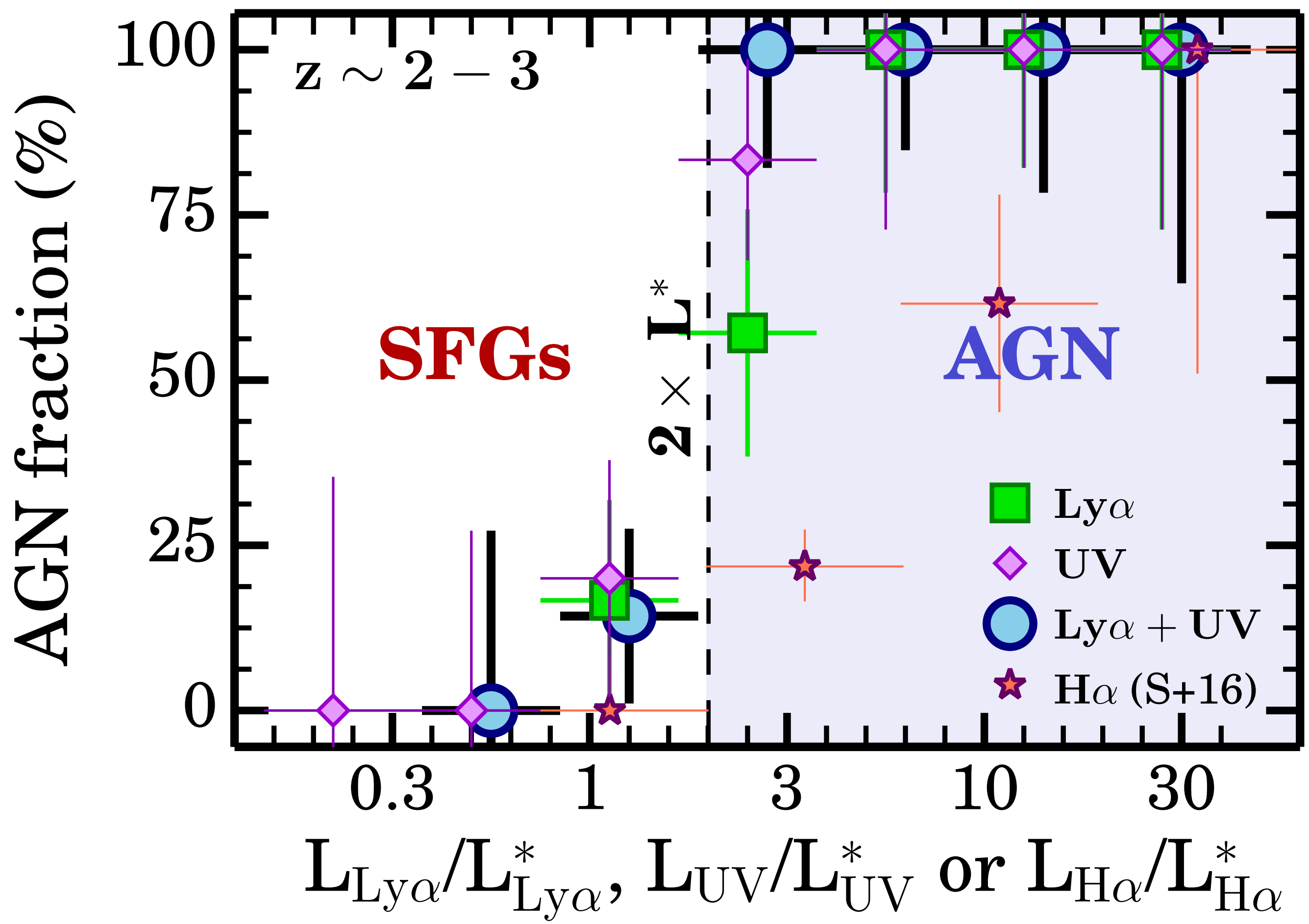
Stack	NV/Lyα	CIV/HeII	CIII]/HeII	log U	Gas Metallicity	Burst Age (Myrs)	Power-law α	$T_{\rm eff}$ (kK)
Full sample	0.11 ± 0.01	1.7 ± 0.2	5.2 ± 0.4	$-0.7^{+0.5}_{-0.4}$	$8.7^{+0.3}_{-0.1}$	6^{+25}_{-4}	$-1.4^{+0.3}_{-0.3}$	150^{+10}_{-50}
All SFGs	< 0.16	2.9 ± 0.8	4.8 ± 1.4	$-3.0^{+1.6}_{-0.9}$	$8.2^{+0.5}_{-0.3}$	20^{+40}_{-15}	—	—
All AGNs	0.11 ± 0.02	2.3 ± 0.2	3.0 ± 0.2	$0.6^{+0.5}_{-0.5}$	$8.8^{+0.1}_{-0.1}$	—	$-1.4^{+0.4}_{-0.2}$	70^{+70}_{-10}
$42.6 <$ Lyα < 43.3	0.05 ± 0.02	2.5 ± 0.9	2.5 ± 0.8	$-1.3^{+0.1}_{-0.4}$	$7.5^{+0.5}_{-0.1}$	4^{+2}_{-2}	$-1.7^{+0.3}_{-0.1}$	130^{+20}_{-20}
$43.3 <$ Lyα < 44.2	0.22 ± 0.02	2.0 ± 0.1	2.6 ± 0.2	$-0.6^{+0.1}_{-0.1}$	$8.7^{+0.1}_{-0.1}$	3^{+1}_{-2}	$-1.5^{+0.3}_{-0.3}$	155^{+5}_{-5}

Brightest LAES at z~2-3: maximal starbursts and AGN

Spectroscopic follow-up with Keck, VLT and WHT:

see full discussion in: Sobral et al. 2018b, MNRAS, 477, 2817

Maximal starburst output before dust limits observed L: ~20 $M_{\odot}$/yr at z~2-3

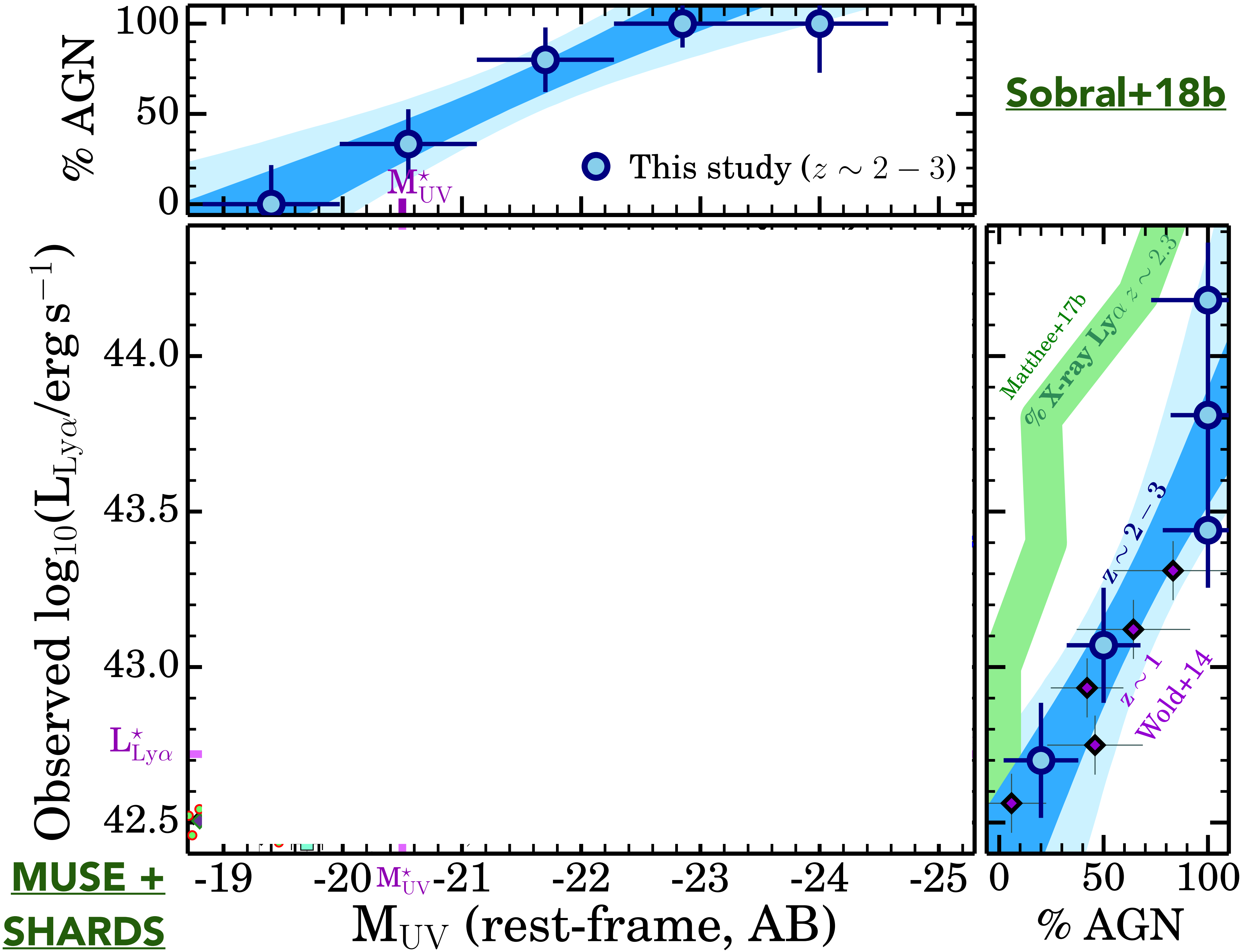


AGN fraction among LAEs rises with UV and Lyα luminosities:

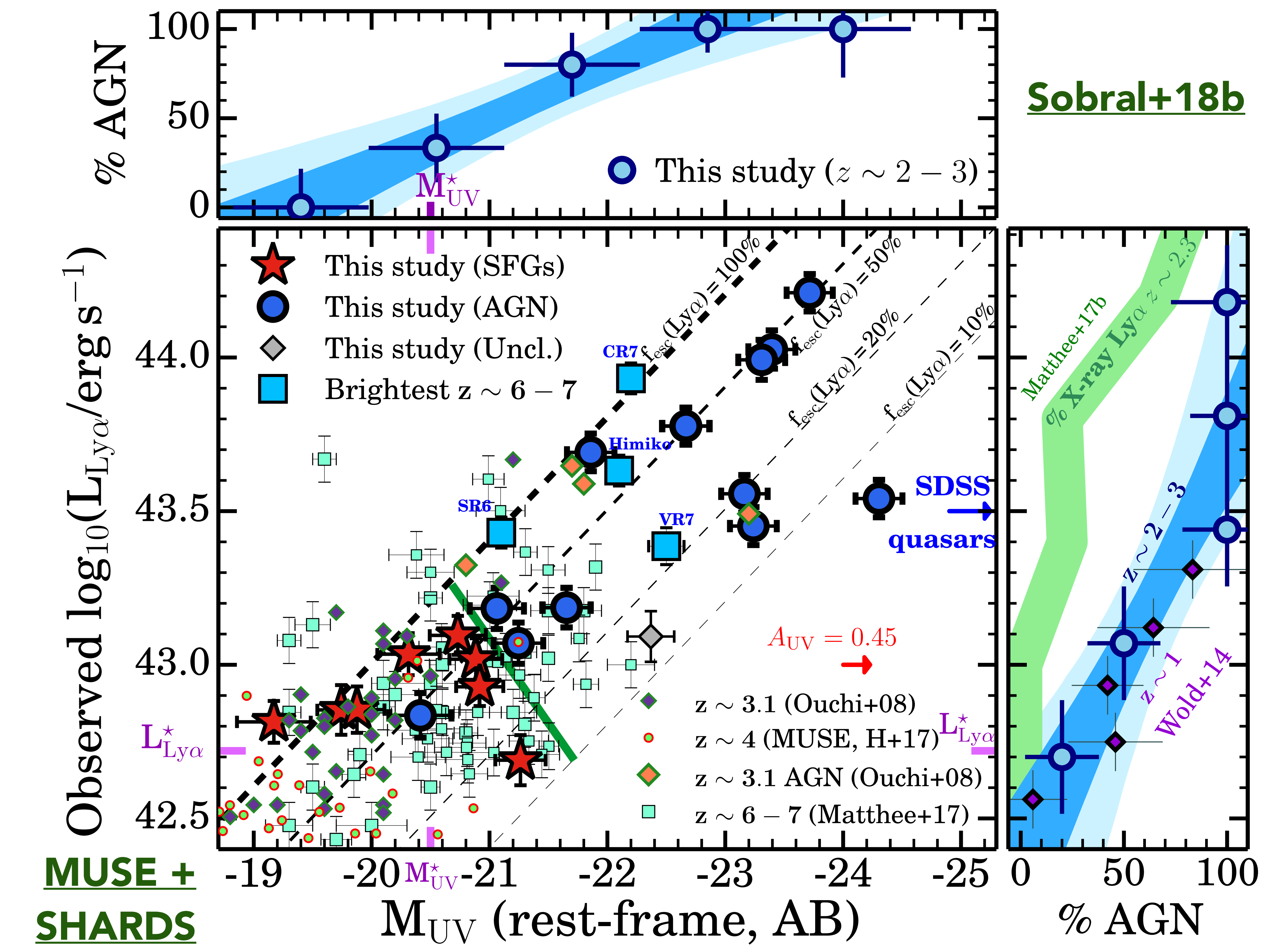
Limit set by maximal starburst output before dust limits it vs AGN.

Likely evolves with redshift: higher limit at high-z! (Himiko, CR7)

see also Sobral+2016b



% AGN
100
50
0
This study ($z \sim 2-3$)
$M^{\star}_{UV}$
Sobral+18b
Observed $\log_{10}(L_{Ly\alpha}/\mathrm{erg\,s^{-1}})$
44.0
43.5
43.0
42.5
$L^{\star}_{Ly\alpha}$
-19
-20
-21
-22
-23
-24
-25
M_{UV} (rest-frame, AB)
MUSE +
SHARDS
Matthee+17b
% X-ray Lyα $z \sim 2.3$
$z \sim 2-3$
$z \sim 1$
Wold+14



Sobral+18b
% AGN
This study (z ~ 2 − 3)
$M^{\star}_{UV}$
This study (SFGs)
This study (AGN)
This study (Uncl.)
Brightest z ~ 6 − 7
CR7
Himiko
SR6
VR7
$f_{esc}(Ly\alpha)=100\%$
$f_{esc}(Ly\alpha)=50\%$
$f_{esc}(Ly\alpha)=20\%$
$f_{esc}(Ly\alpha)=10\%$
SDSS quasars
$A_{UV}=0.45$
z ~ 3.1 (Ouchi+08)
z ~ 4 (MUSE, H+17)
z ~ 3.1 AGN (Ouchi+08)
z ~ 6 − 7 (Matthee+17)
$L^{\star}_{Ly\alpha}$
Observed $\log_{10}(L_{Ly\alpha}/\mathrm{erg\,s^{-1}})$
M_{UV} (rest-frame, AB)
Matthee+17b
% X-ray Lyα z ~ 2.3
z ~ 2 − 3
z ~ 1
Wold+14
MUSE + SHARDS

In which haloes do LAEs live in?

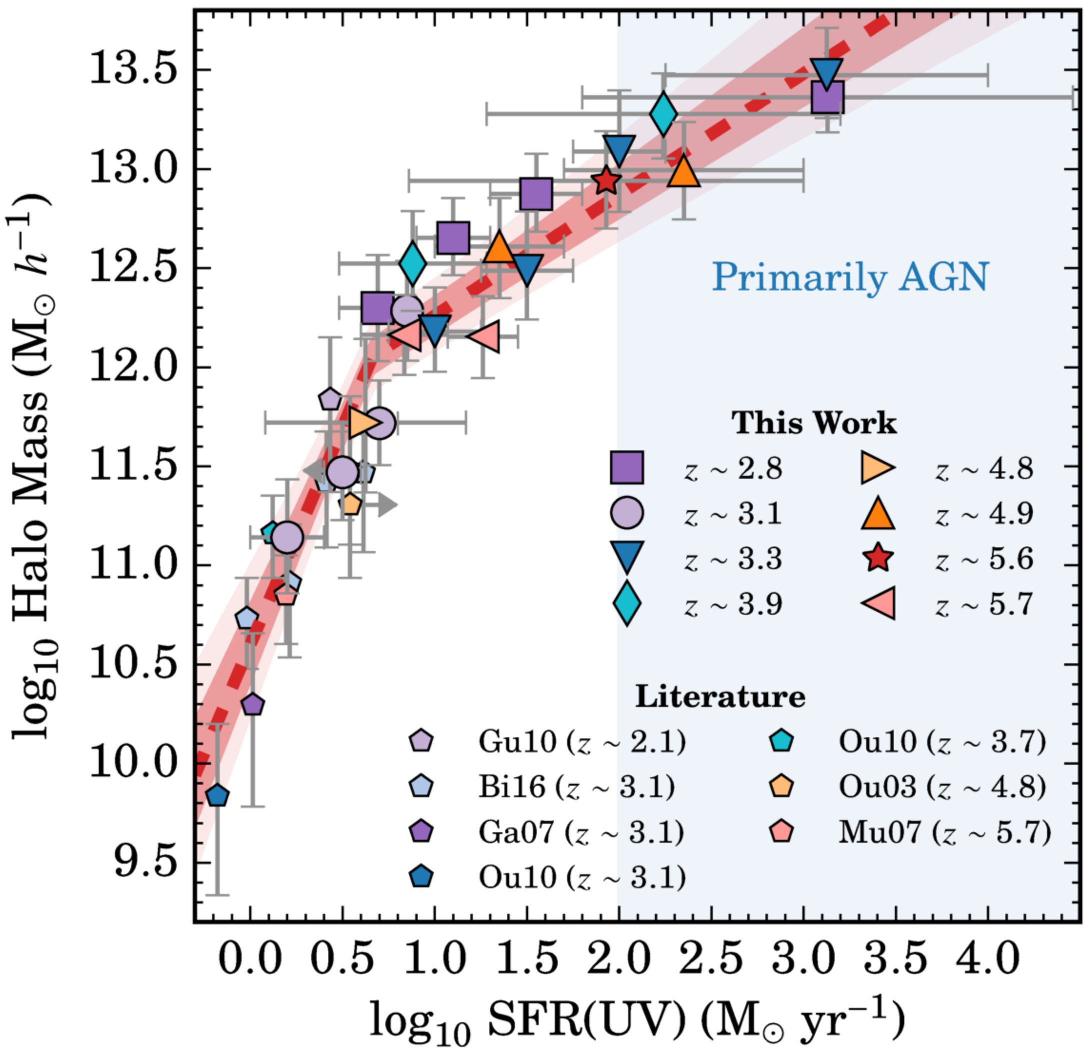
- Clustering of LAEs with large samples from z~2 to z~7 from faint to bright sources covering a co-moving volume of ~10^8 Mpc^3

Khostovan, Sobral et al. 2019, arXiv:1811.00556

No single answer: depends on luminosity or SFR!

- LAEs hosted from 10^{10} M_{o} to $10^{13.5}$ M_{o} dark matter haloes
- From SF to AGN hosts

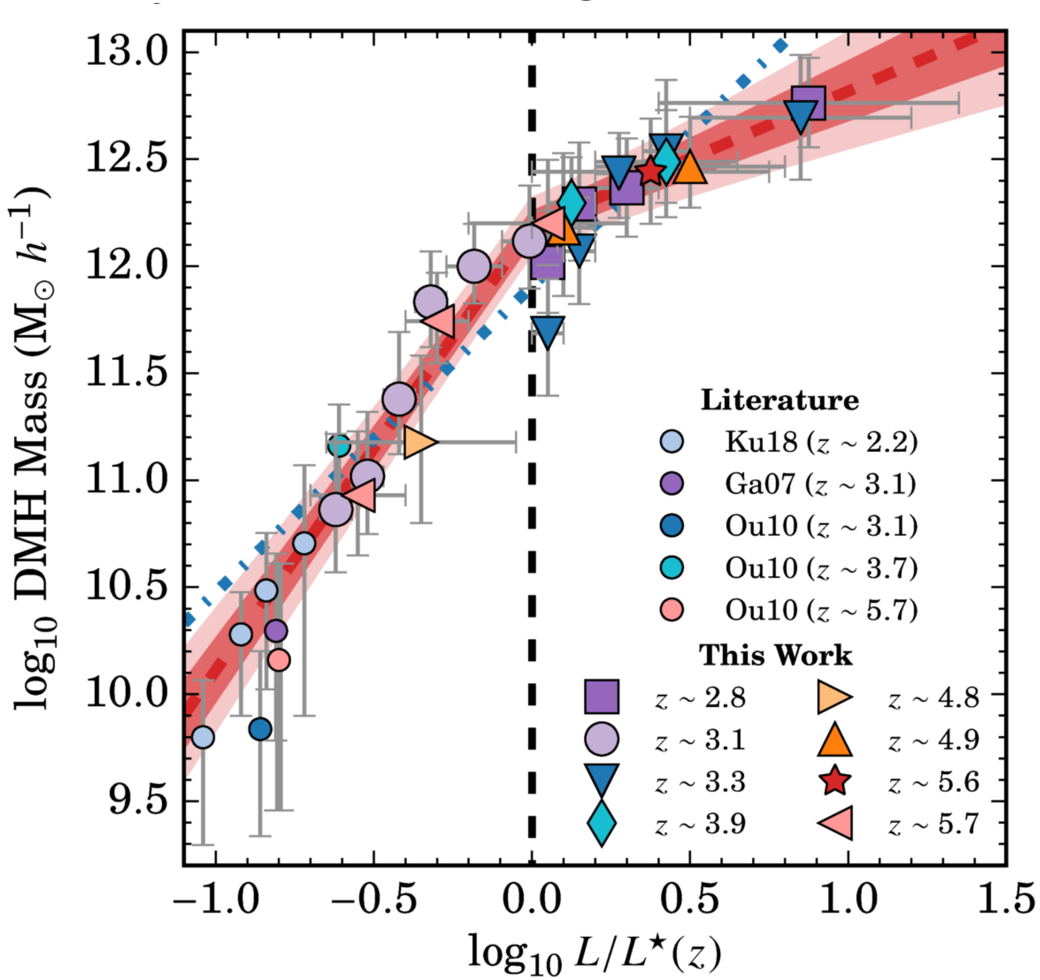
Khostovan, Sobral et al. 2019, arXiv:1811.00556



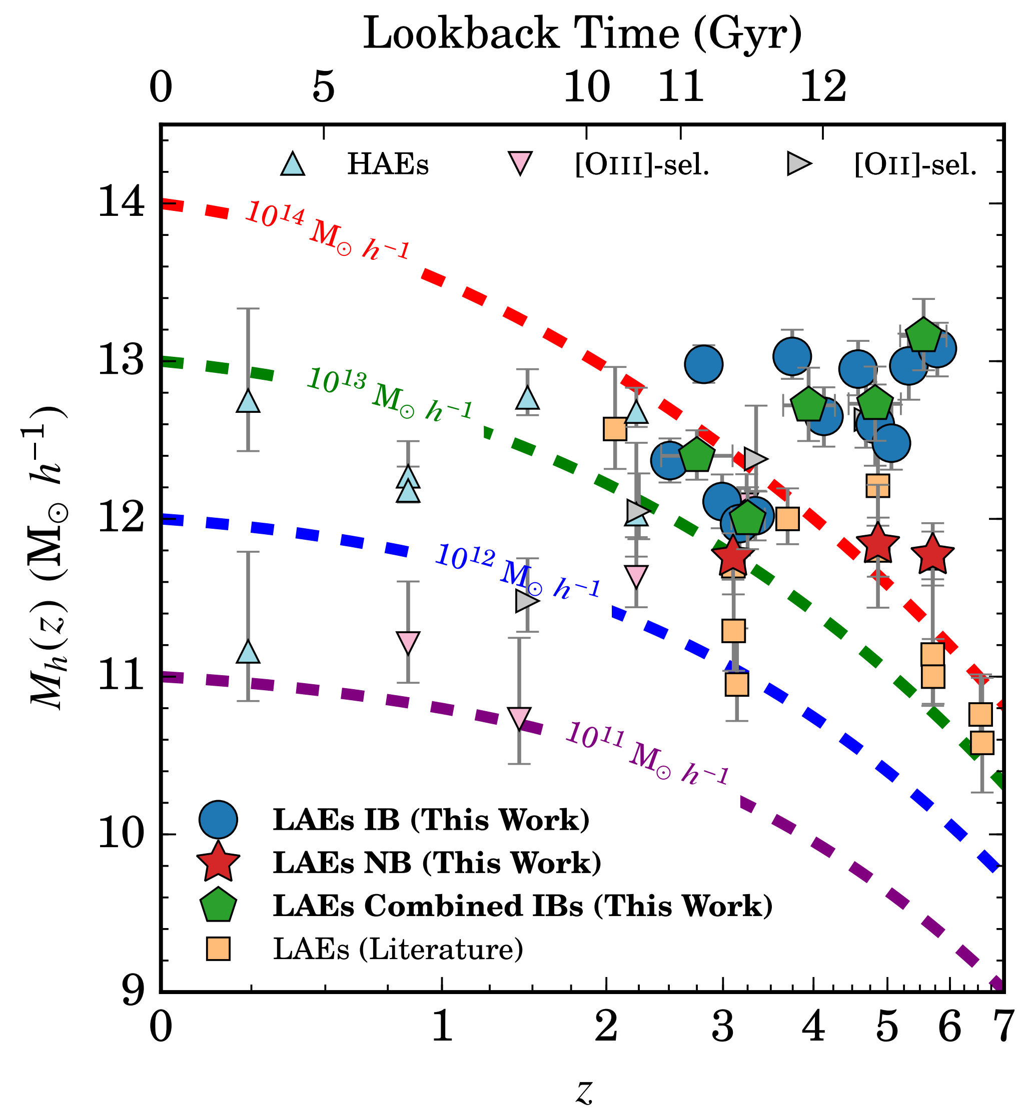
Location in luminosity function (L/L*) predicts M_{halo}

LAEs: Progenitors of all kinds of galaxies, depending on their UV and Lyα luminosity

From proto-clusters at high L to MW and Magellanic clouds

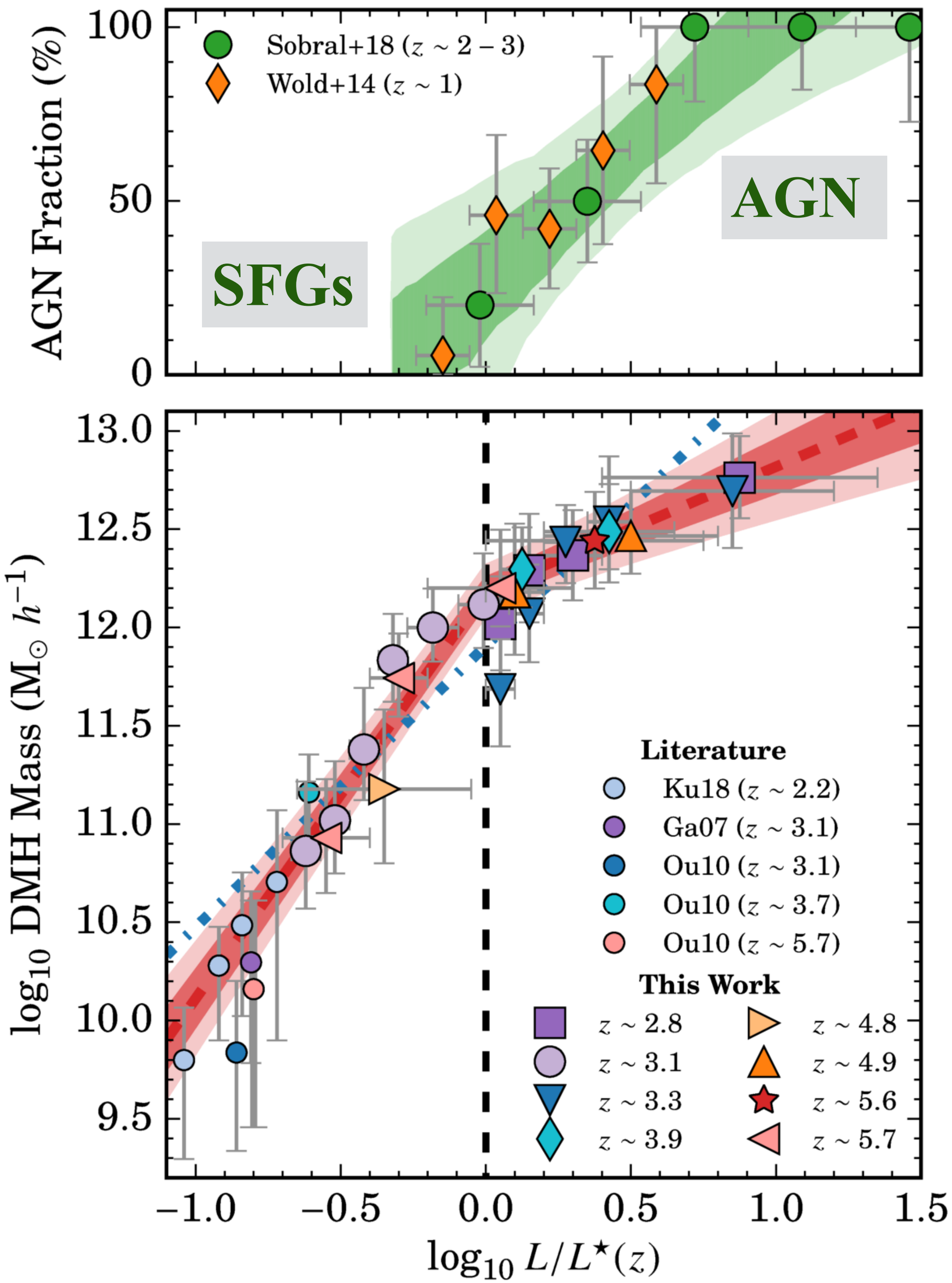


Khostovan, Sobral et al. 2019, arXiv:1811.00556

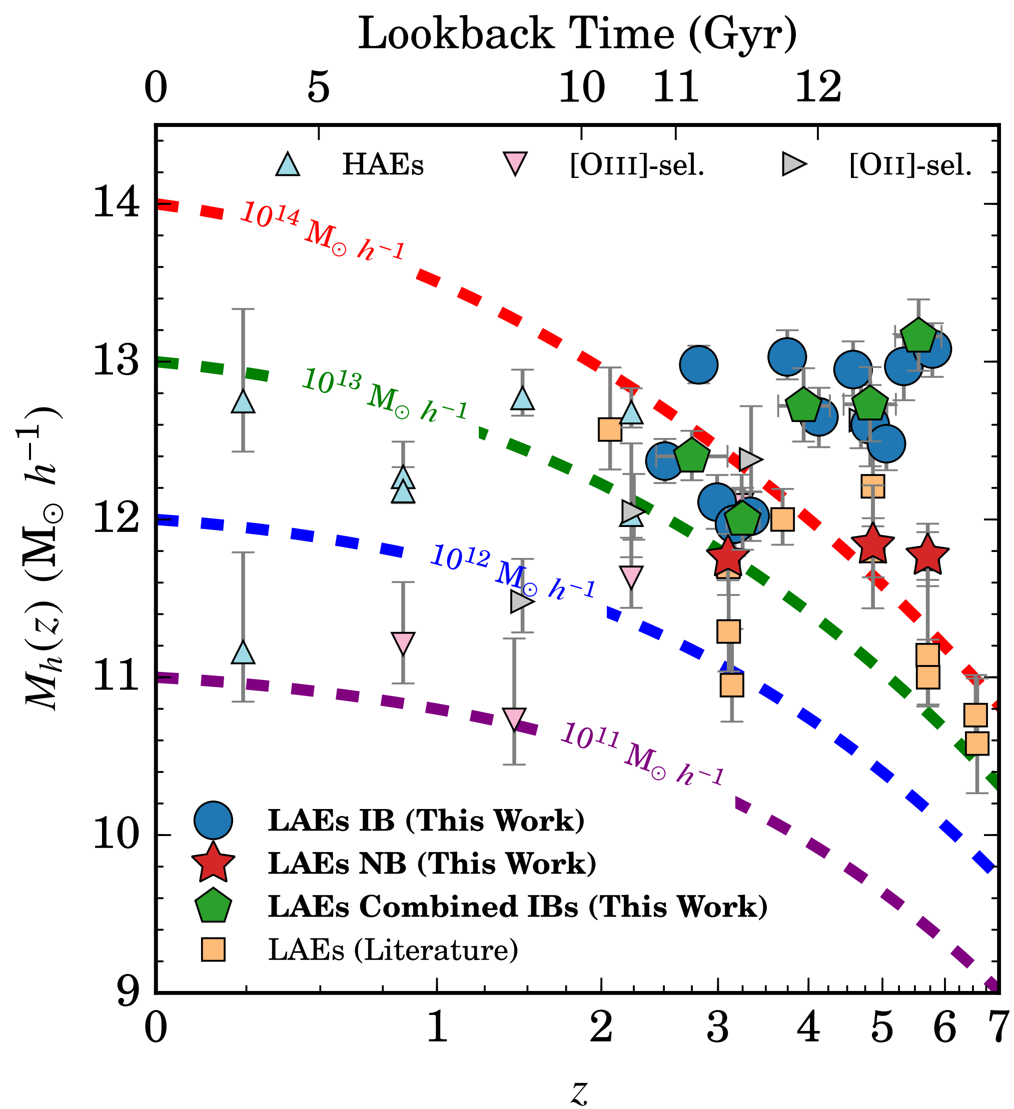


See also: **Sobral+2010; Khostovan, Sobral +2018; Cochrane, Best, Sobral+2017**

Location in luminosity function (L/L*) predicts M_{halo}



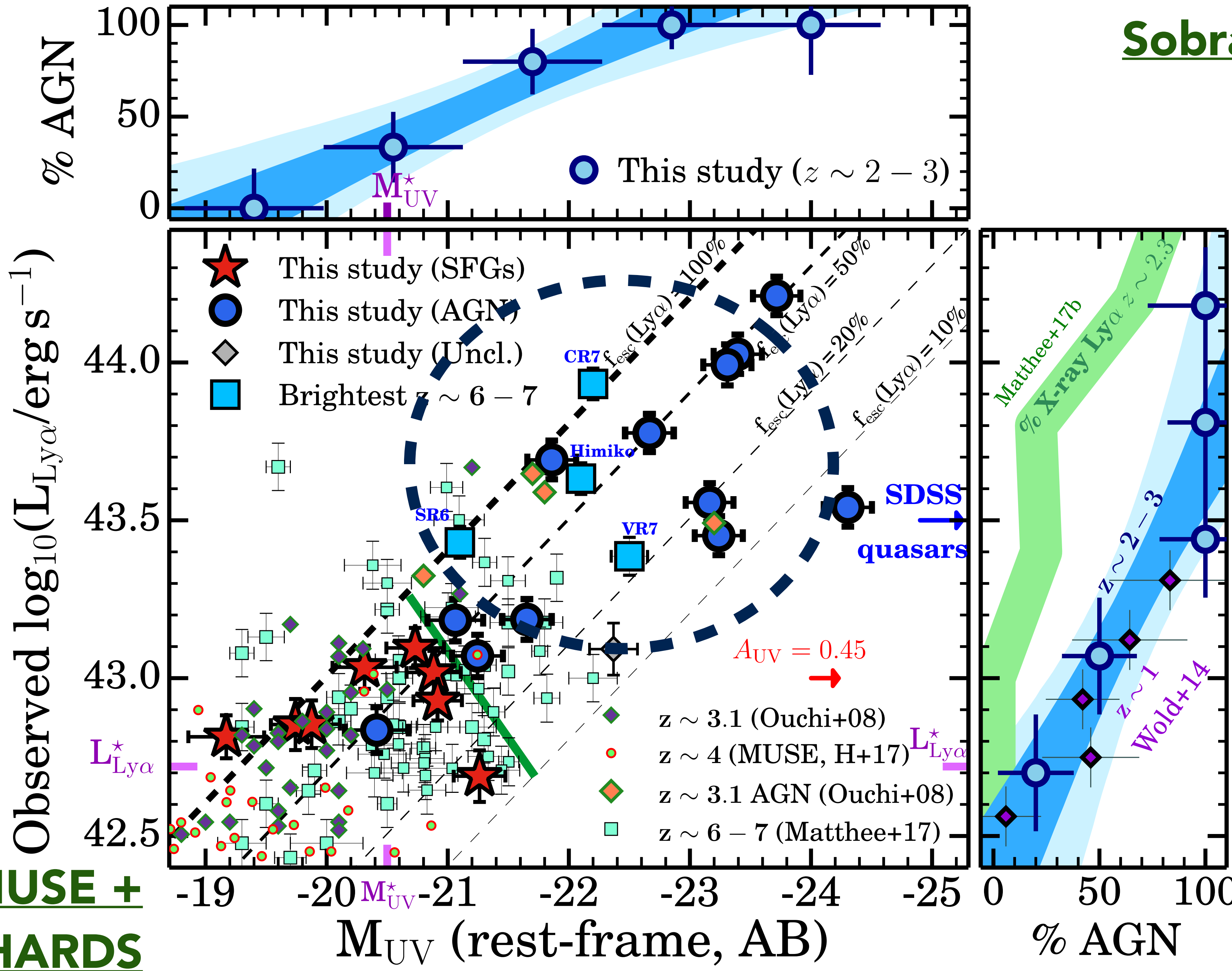
Khostovan, Sobral et al. 2019, arXiv:1811.00556



Progenitors of all kinds of galaxies

See also: **Sobral+2010; Khostovan, Sobral +2018; Cochrane, Best, Sobral+2017**

Luminous LAEs at z~5-7: are they AGN? Evolution?



Sobral+18b

MUSE + SHARDS

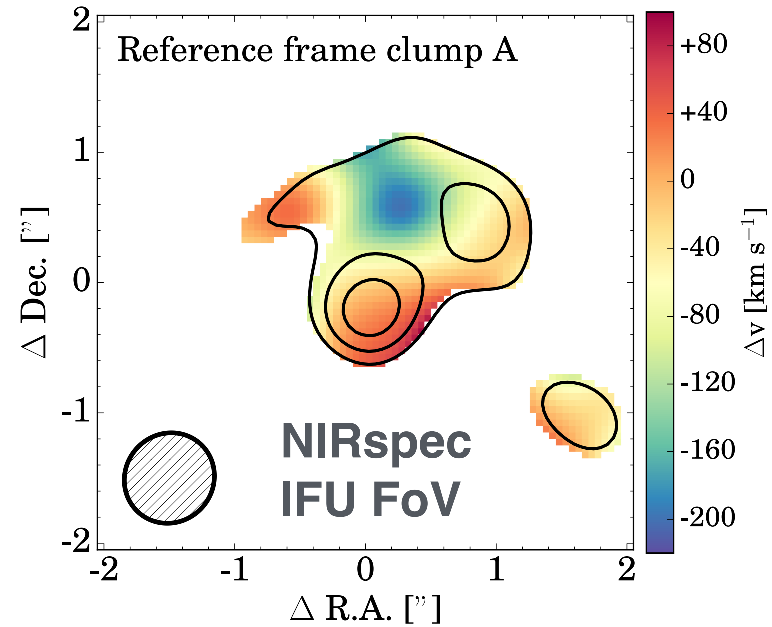
THE FUTURE IS RESOLVED: ALMA + HST+ JWST/NIRSPEC

CR7 (Sobral+15):
z=6.60, very high
Lyα EW

UV bright
3 UV components

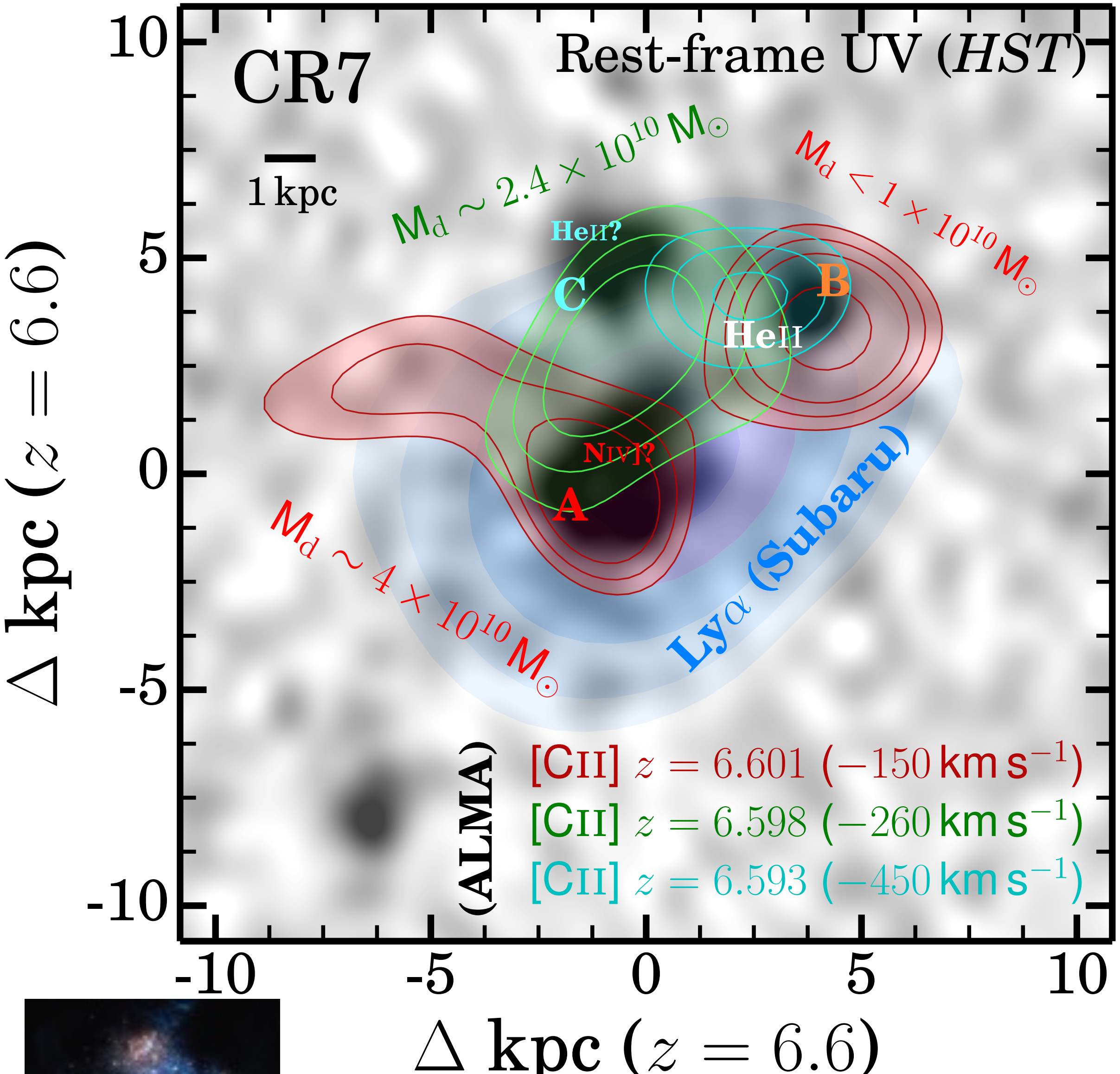
4 [CII] components

See Jorryt's
talk tomorrow



Sobral, Matthee et al. 2019, MNRAS, 482, 2422

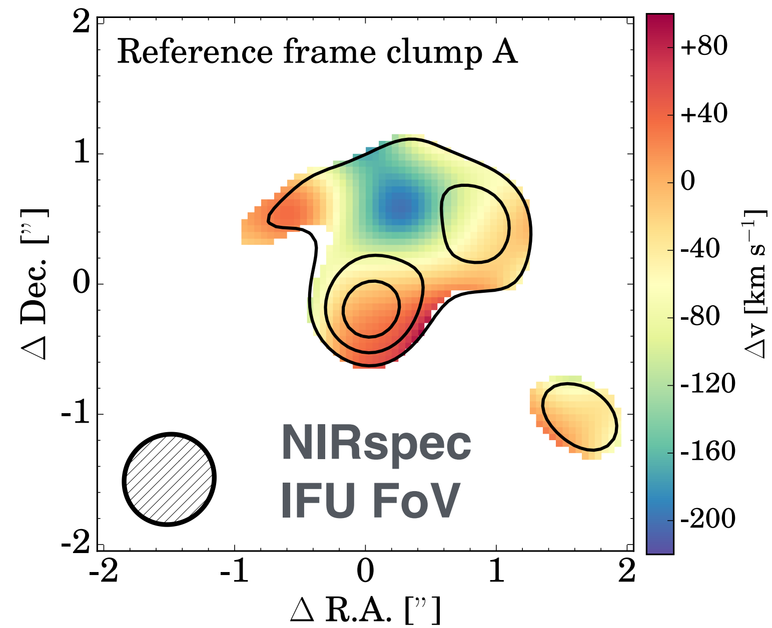
THE FUTURE IS RESOLVED: ALMA + HST+ JWST/NIRSPEC



CR7 (Sobral+15):
z=6.60, very high Lyα EW

UV bright
3 UV components

4 [CII] components



Sobral, Matthee et al. 2019, MNRAS, 482, 2422

Main take-home points

- Typical EWs of (non-resonant) emission lines go up by 2 dex: <u>**evolution in typical stellar populations + ISM**</u>?
- Current Hα + other lines view - <u>**the future is resolved, and therefore complicated: let's deal with it**</u>
- Lyα selected sources pick up high escape fraction sources (young) at any redshift + a population of AGN
- **LAEs: crucial in driving re-ionisation, whether by "oLAEgarcs" (e.g. Naidu+2019) or by the fainter LAEs** as **~all LyC leakers should be Lyα emitters**
- There's **too much interesting physics in Lyα** (and other lines) to use it (them) as simple redshift machine(s). Like having a Ferrari whose sole purpose is to cross streets

Conclusions/take-home points

- **Lyman-α at high-z**: why, what for + (how) can we use it?
- ***CALYMHA***: empirical calibration of **Lyα with Hα at high-z**
- Large volume surveys for Lyα emitters (LAEs) at z~2-7
- Lyα LF: evolution, luminosity density. At high-z, LAEs “rule”
- Lyα emitters: from star-forming to AGN dominated ~2L*
- Clustering properties: progenitors of all kinds of galaxies
- LAEs in the epoch of re-ionisation: early ionised bubbles
- Resolved results on Lyα, UV and [CII]: ALMA-HST-ALMA: luminous LAEs at z~7 are rapidly assembling centrals