Lyα (&UV) halos of Lyα emitters across environments at z=2.84

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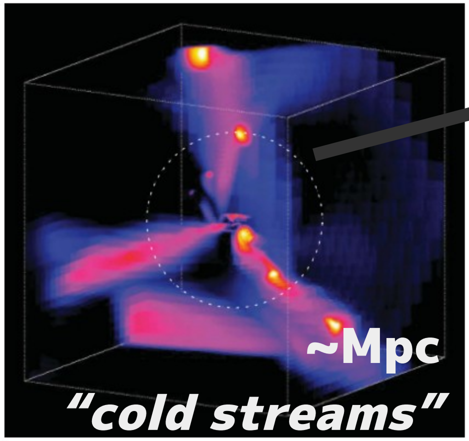
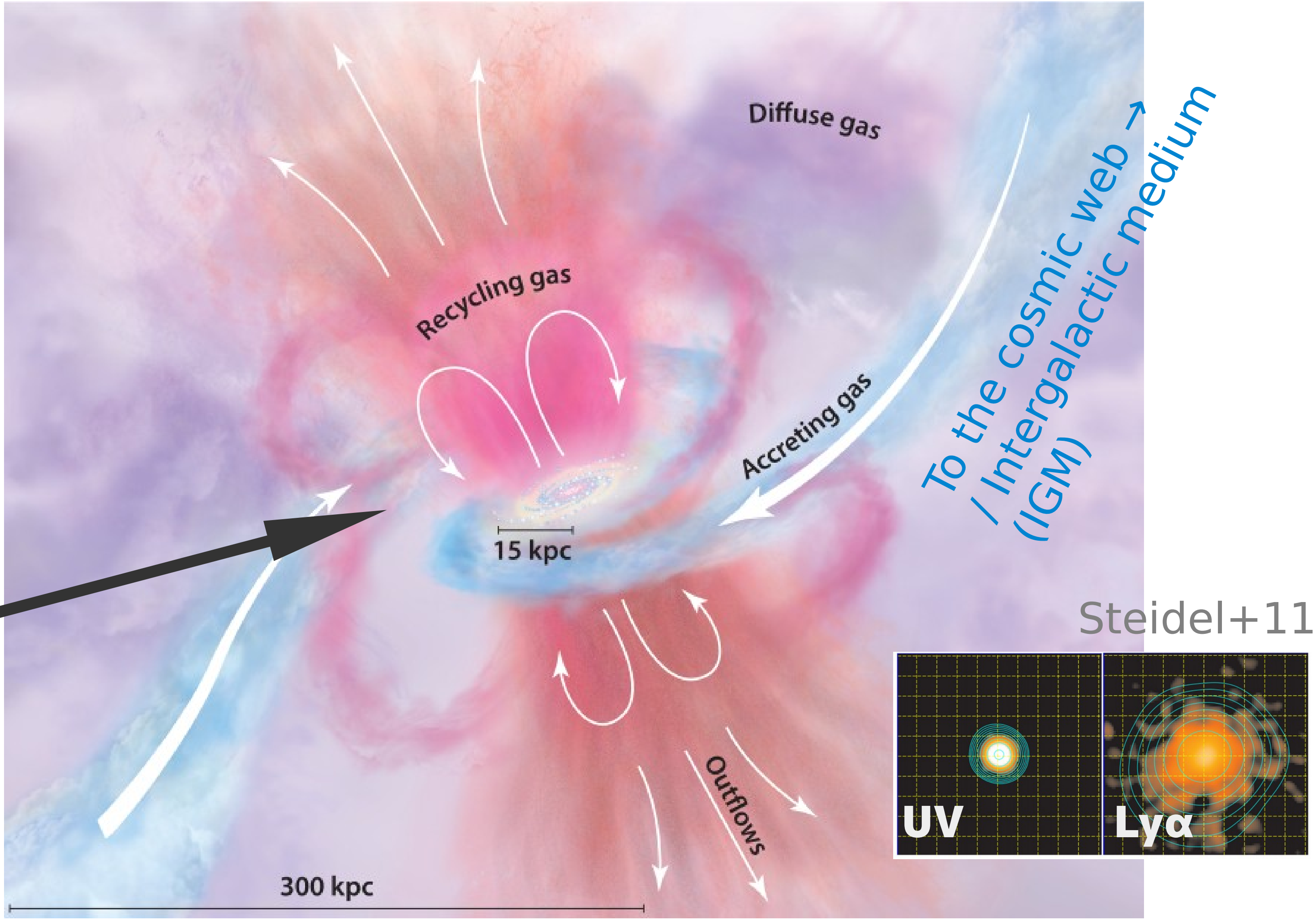
Circumgalactic/Intergalactic Medium (CGM/IGM) and Lyα halo (LAH)

- Gas accretion along the cosmic web governs early galaxy evolution
- Obs. of the IGM/CGM (**=fuel for SF**) is very important
- Can be observed with Lyα emission as **Lyα halo (LAH)**



Dekel+09



Tumlinson, Peeples, and Werk, ARAA, 2017

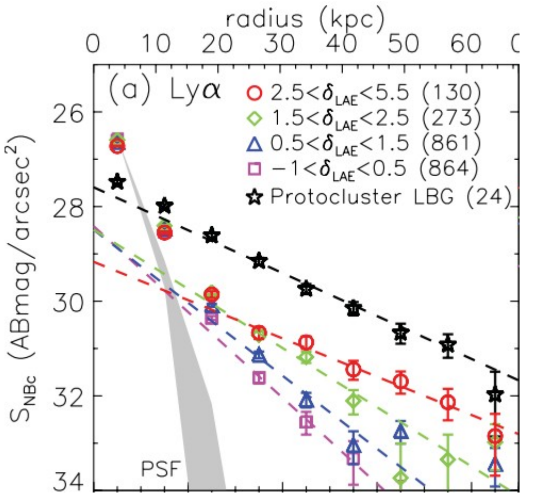
Steidel+11

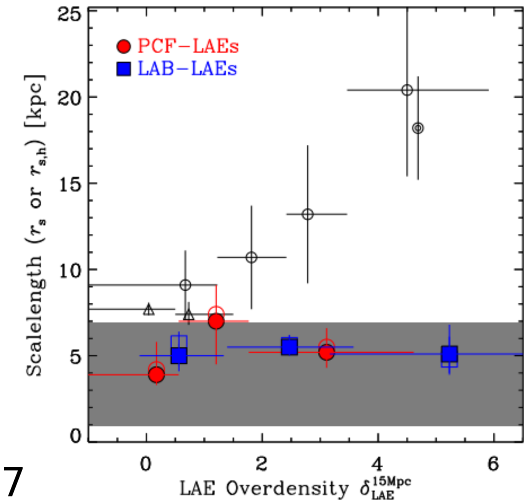
Lyα halos of LAEs across environments

- **Are LAHs larger in denser environments?**

  If so, this has implications for the environmental segregation at z=0

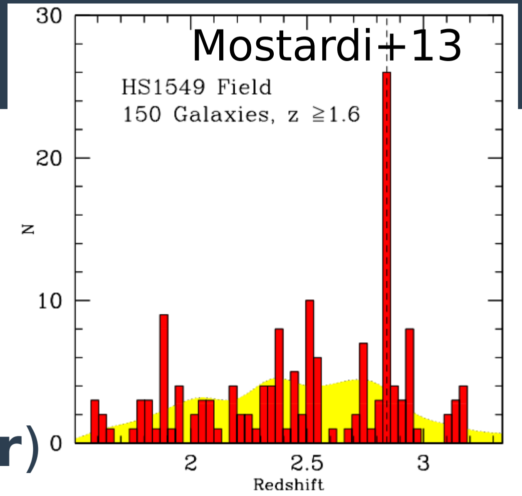
  But no consensus yet!
- Target obs. for more PCs are required
  - Huge FoV of **HSC** enables us to simultaneously probe various environments





Matsuda+12 vs Xue+17

Target Field & LAE Detection

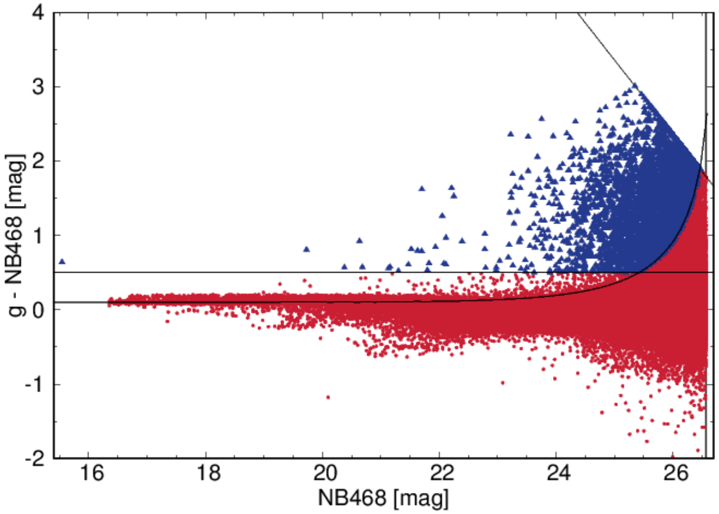


Target: the HS1549 protocluster @ z=2.84)
hyperluminous QSO HS1549+1919 is at its center
(e.g., Steidel+11, Mostardi+13)

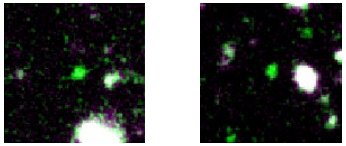
Observed with **Subaru/HSC**, g(**2.2hr**) and NB468(**6.3hr**)
→ Data reduced with HSC pipeline (hscPipe 4.0.5)

Source detection & photometry with
Source Extractor (Bertin & Arnouts 96)

- **LAE selection criteria (2.815<z<2.887):**
  - NB < 26.57(5σ)
  - G – NB > max{0.5, 0.1+4σ(G-NB)}
    (rest $EW_{Ly\alpha}$ >12Å)

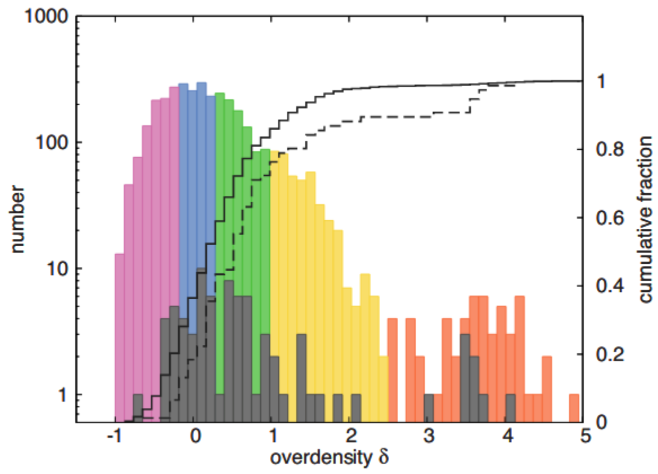


→ 3490 LAEs found



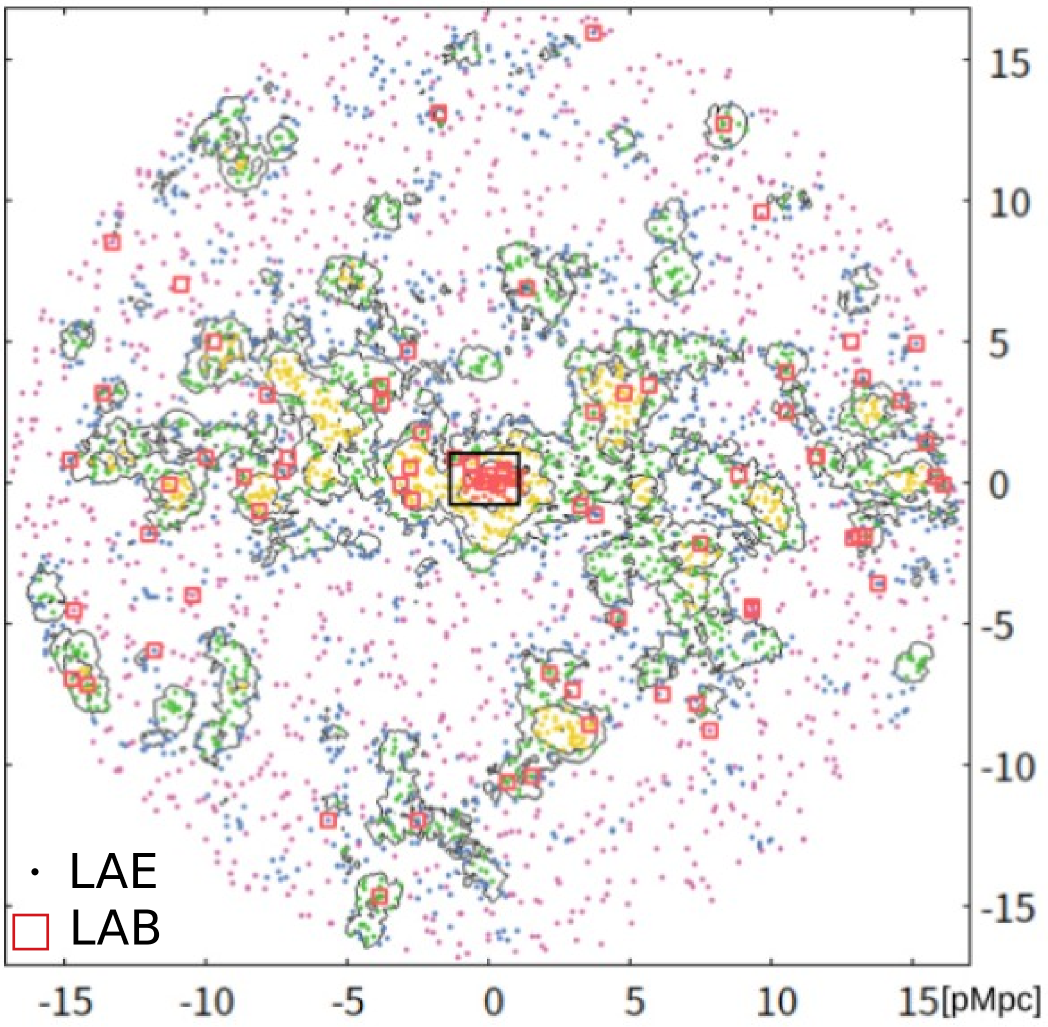
Distribution of LAEs & LABs

- Filamentary structure
- Overdensity at the center
  - see Kikuta+2019, PASJ, 71, L2

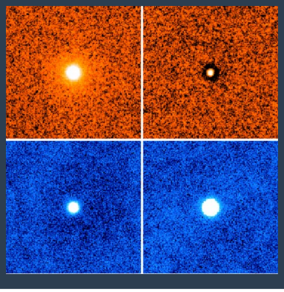


KS-test p-value:0.00173

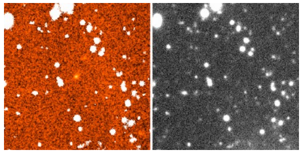
※$\delta_{gal}=n/n_{ave}-1$, n is the number of LAEs within a 1.8’ aperture at a given point

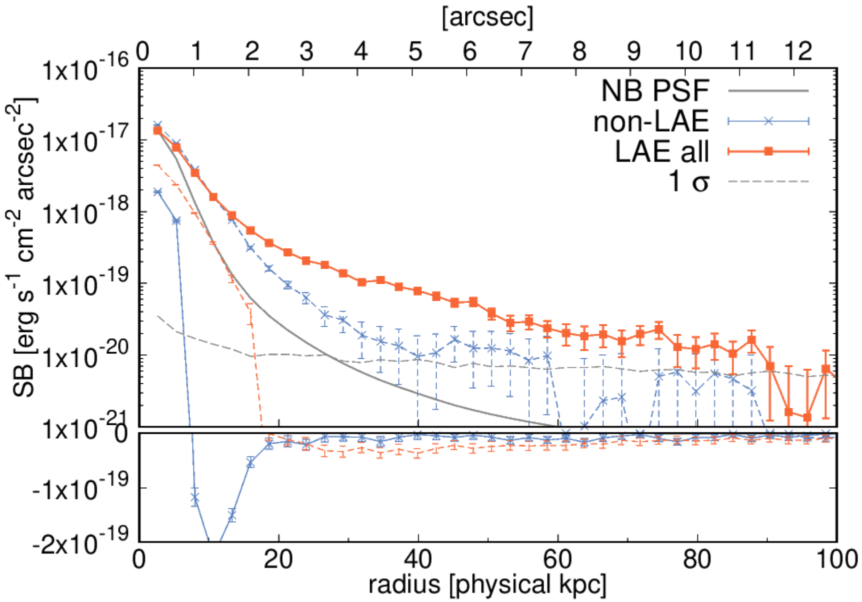


Stacking Analyses



- Use cutout Lyα images of LAEs (sky mesh size=30”) with continuum sources masked
- Stack Lyα & continuum images with IRAF imcombine (median, no clipping)
- Sky noise behaves well (noise ∝ $\sim N^{-1/2}$)
- “Non-LAE” sample is constructed to check total systematics (see Momose+14)
- **Detect diffuse Lyα emission down to $\sim 10^{-20}$ erg/s/cm²/arcsec²**



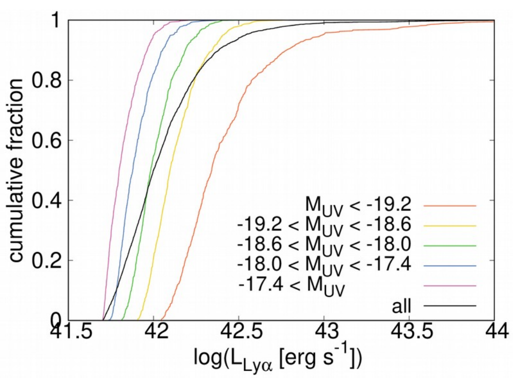


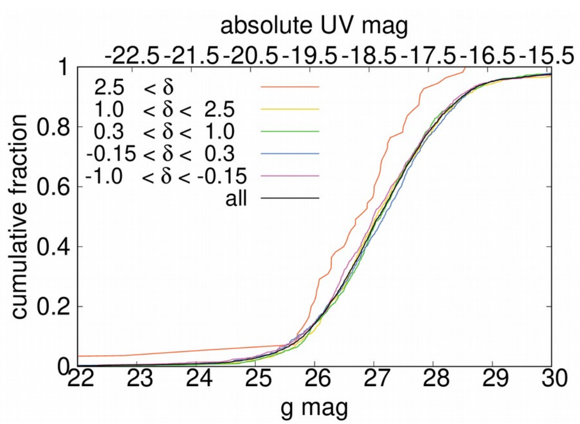
solid: Lyα, dashed: Cont.

LAH Dependence on Various Properties

- Divide LAEs into 5 groups according to their photometric properties
- “Distance from the HLQSO” is for checking the impact of strong radiation field made by the QSO
- Note the correlations between quantities

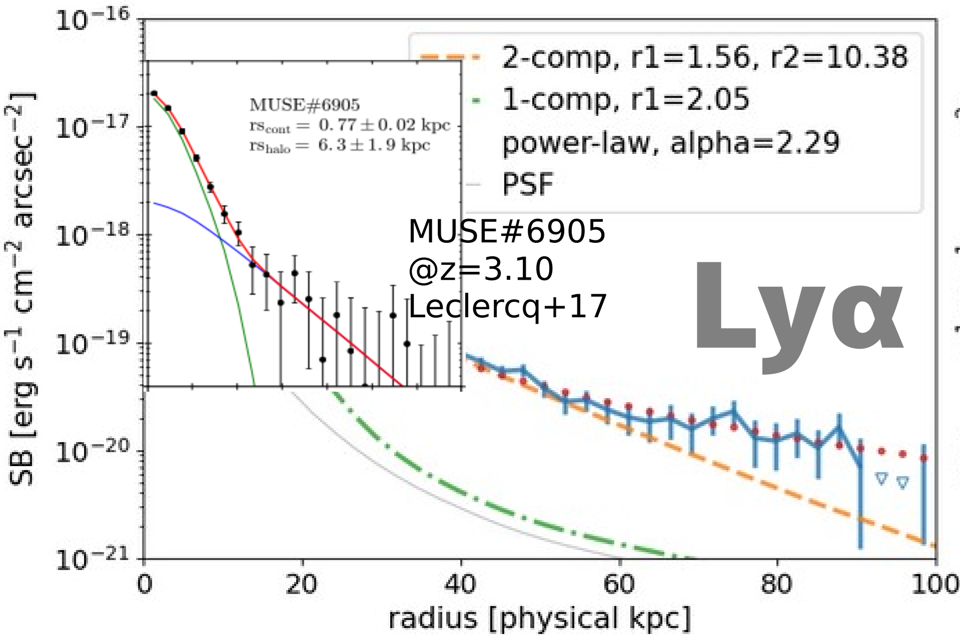
quantity	criteria	N
UV magnitude	$M_{\rm UV} < -19.2$	690
	$-19.2 < M_{\rm UV} < -18.6$	696
	$-18.6 < M_{\rm UV} < -18.0$	773
	$-18.0 < M_{\rm UV} < -17.4$	648
	$-17.4 < M_{\rm UV}$	683
Lyα luminosity	$42.25 < \log L_{\rm Ly\alpha}$	647
	$42.05 < \log L_{\rm Ly\alpha} < 42.25$	833
	$41.95 < \log L_{\rm Ly\alpha} < 42.05$	610
	$41.85 < \log L_{\rm Ly\alpha} < 41.95$	645
	$\log L_{\rm Ly\alpha} < 41.85$	755
Lyα equivalent width	$\mathrm{EW}_{0,\rm Ly\alpha} < 30$Å	686
	30Å$< \mathrm{EW}_{0,\rm Ly\alpha} < 55$Å	727
	55Å$< \mathrm{EW}_{0,\rm Ly\alpha} < 90$Å	698
	90Å$< \mathrm{EW}_{0,\rm Ly\alpha} < 160$Å	735
	160Å$< \mathrm{EW}_{0,\rm Ly\alpha}$	644
Environment	$2.5 < \delta$	55
	$1.0 < \delta < 2.5$	433
	$0.3 < \delta < 1.0$	944
	$-0.15 < \delta < 0.3$	1076
	$-1.0 < \delta < -0.15$	982
Distance from the HLQSO	$d_{\rm Q} < 6.2$ pMpc	679
	6.2 pMpc $< d_{\rm Q} < 9.5$ pMpc	739
	9.5 pMpc $< d_{\rm Q} < 12.0$ pMpc	633
	12 pMpc $< d_{\rm Q} < 14.8$ pMpc	778
	14.8 pMpc $< d_{\rm Q} < 18.0$ pMpc	661

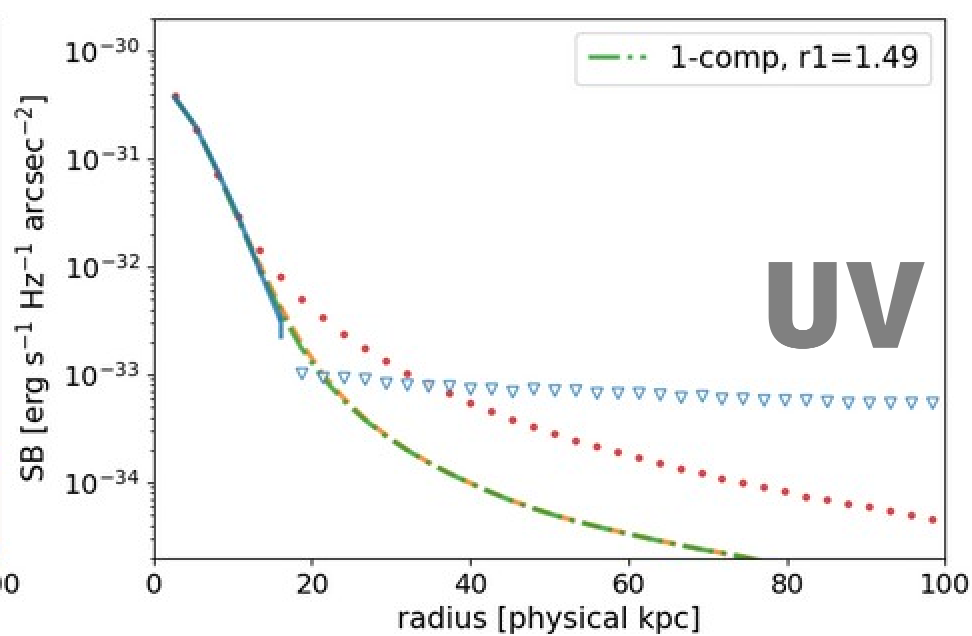


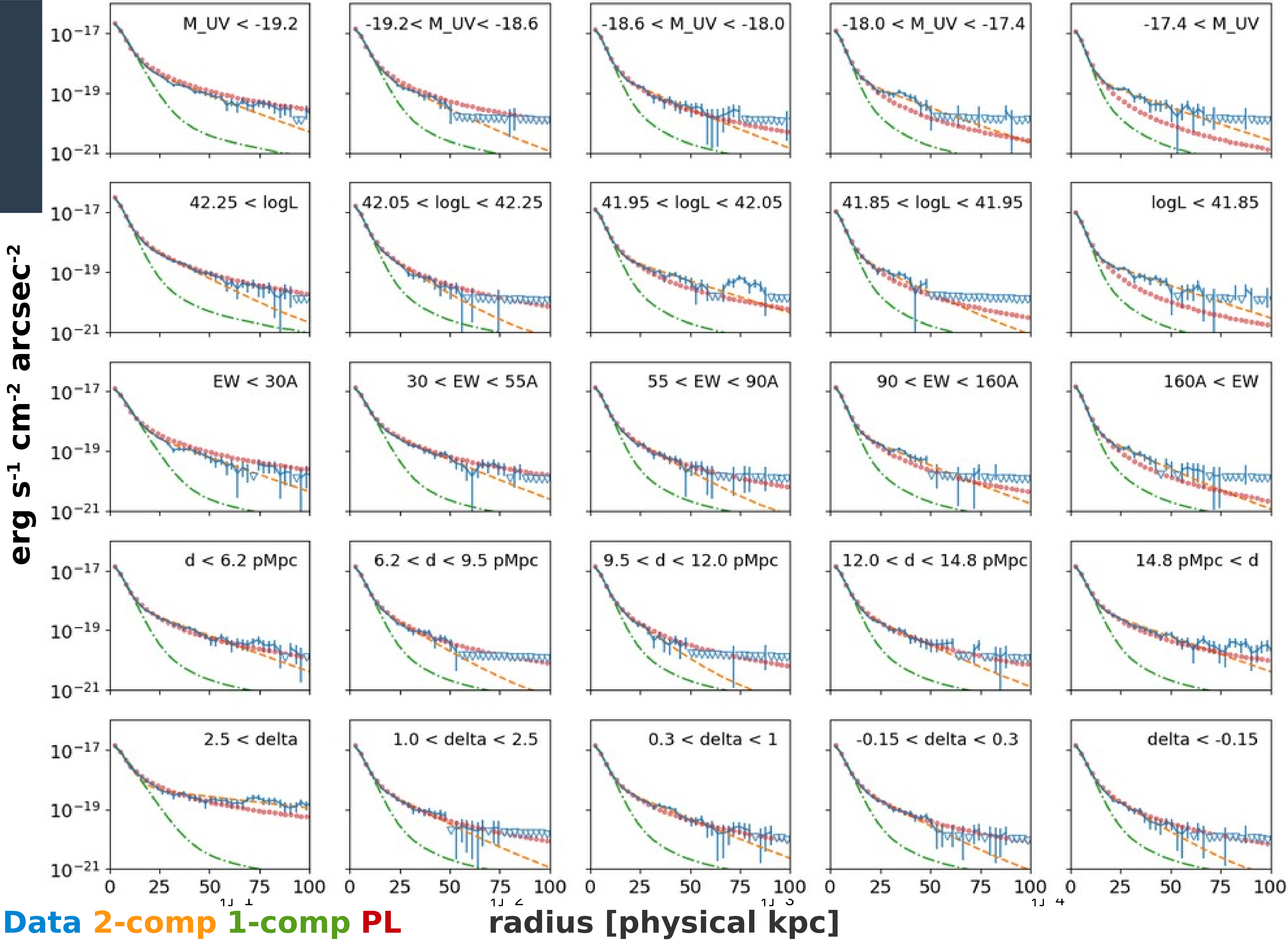


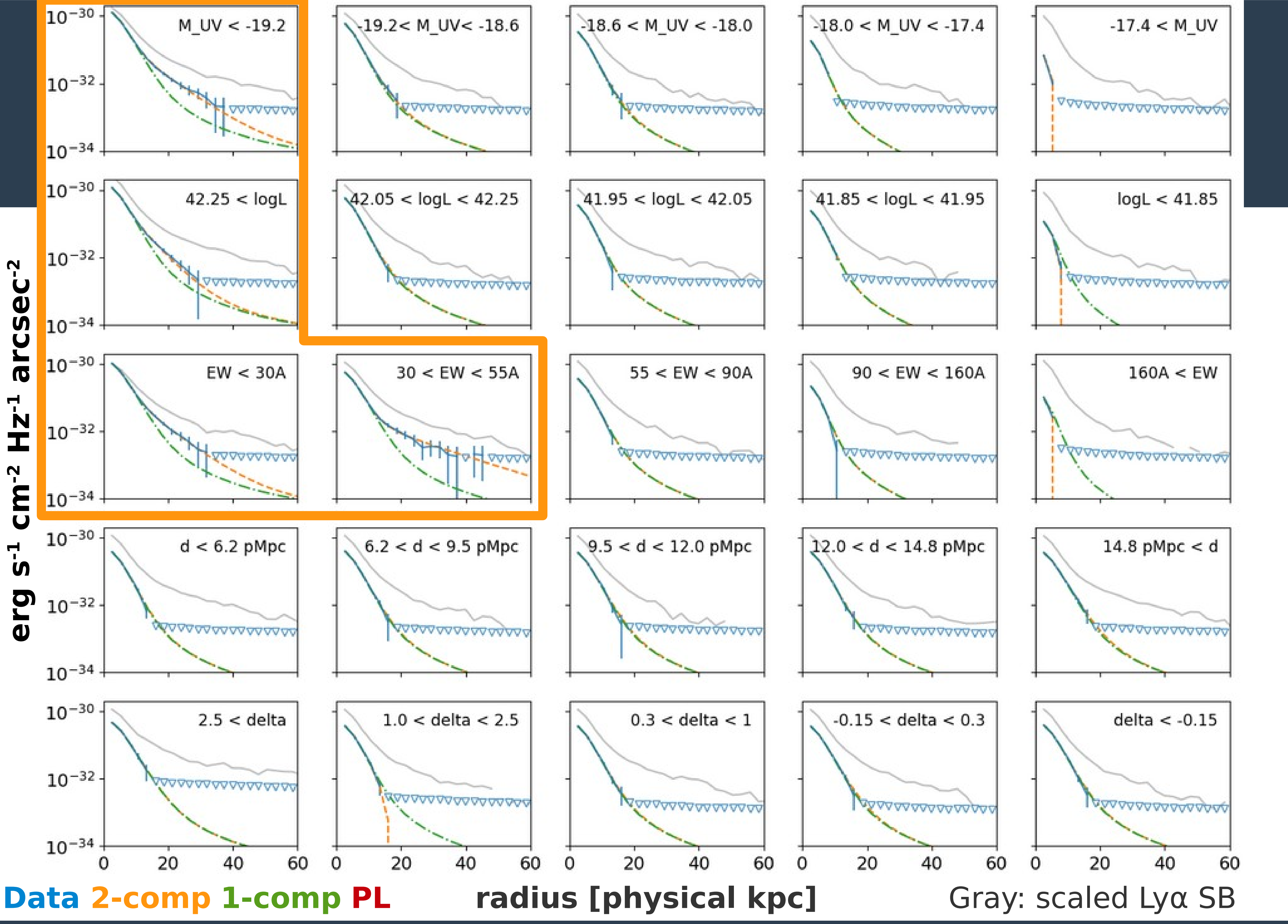
Fitting exponential functions

- SB radial profiles are fit with the following functions:
  - **2-component exponential**: PSF*(C_1×exp(-r/r_1))
  - **1-component exponential**: PSF*(C_1×exp(-r/r_1)+C_2×exp(-r/r_2))
  - **Power-law**: PSF*(C_1×$r^{-\alpha}$) as suggested by a model in Kakiichi & Dijkstra 2018



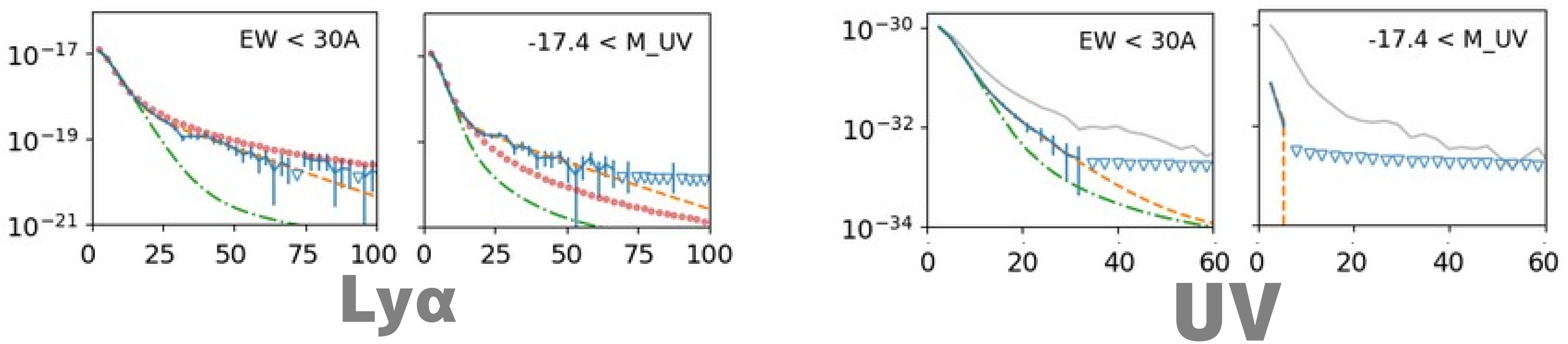



M_UV < -19.2
-19.2< M_UV< -18.6
-18.6 < M_UV < -18.0
-18.0 < M_UV < -17.4
-17.4 < M_UV
42.25 < logL
42.05 < logL < 42.25
41.95 < logL < 42.05
41.85 < logL < 41.95
logL < 41.85
EW < 30A
30 < EW < 55A
55 < EW < 90A
90 < EW < 160A
160A < EW
d < 6.2 pMpc
6.2 < d < 9.5 pMpc
9.5 < d < 12.0 pMpc
12.0 < d < 14.8 pMpc
14.8 pMpc < d
2.5 < delta
1.0 < delta < 2.5
0.3 < delta < 1
-0.15 < delta < 0.3
delta < -0.15
erg s-1 cm-2 arcsec-2
Data 2-comp 1-comp PL
radius [physical kpc]


M_UV < -19.2
-19.2< M_UV< -18.6
-18.6 < M_UV < -18.0
-18.0 < M_UV < -17.4
-17.4 < M_UV
42.25 < logL
42.05 < logL < 42.25
41.95 < logL < 42.05
41.85 < logL < 41.95
logL < 41.85
EW < 30A
30 < EW < 55A
55 < EW < 90A
90 < EW < 160A
160A < EW
d < 6.2 pMpc
6.2 < d < 9.5 pMpc
9.5 < d < 12.0 pMpc
12.0 < d < 14.8 pMpc
14.8 pMpc < d
2.5 < delta
1.0 < delta < 2.5
0.3 < delta < 1
-0.15 < delta < 0.3
delta < -0.15
erg s-1 cm-2 Hz-1 arcsec-2
Data 2-comp 1-comp PL
radius [physical kpc]
Gray: scaled Lyα SB

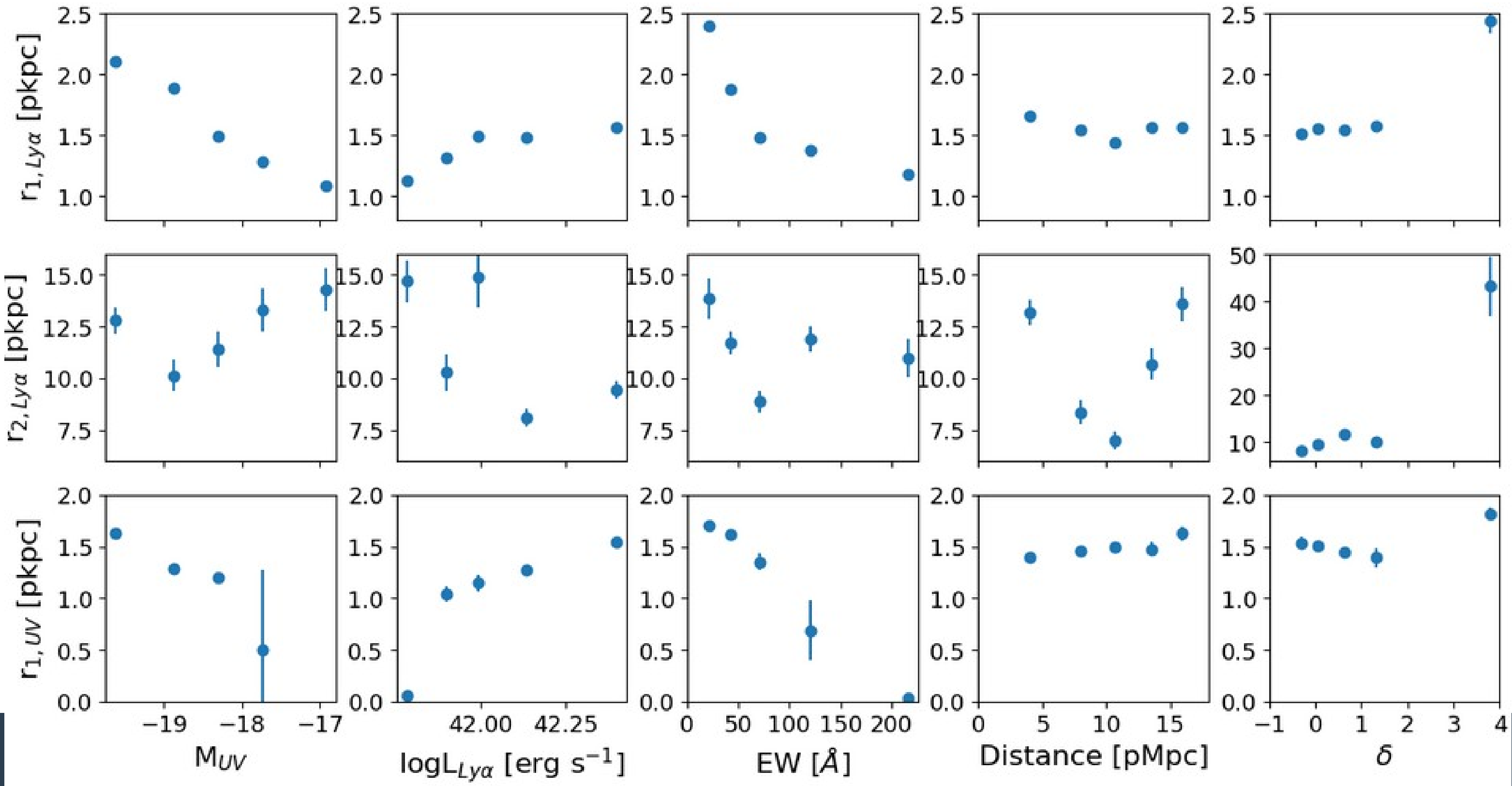
Fitting exponential functions

- **2-comp exp. functions are needed for Lyα SB profiles**, while 1-comp exp. functions are enough for UV in most cases
- Brightest (in Lyα/UV) / lowest-EW LAEs have the **UV 2nd component**
- Power-law sometimes fails to capture the transition from 1st to 2nd component



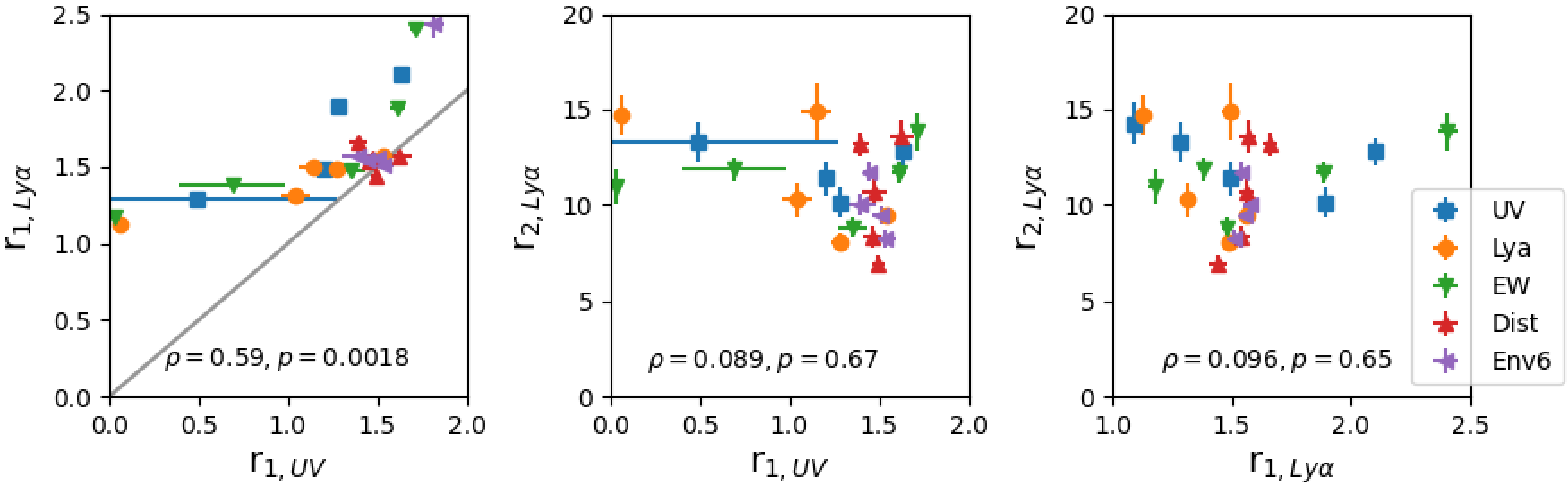
Results of Fitting

- Lyα/UV 1st components correlate with M_{UV}, $L_{Ly\alpha}$, EW
  - Brighter LAEs have larger cores
- Lyα 2nd component behaves stochastically
- Protocluster sample (δ>2.5) stands out



Relation between scalelengths $r_{1,UV}$, $r_{1,Ly\alpha}$, $r_{2,Ly\alpha}$

- Correlation found only for $r_{1,UV}$ - $r_{1,Ly\alpha}$
  - $r_{2,Ly\alpha}$ is difficult to predict
- Common assumption of $r_{1,UV} = r_{1,Lya}$ is not valid (gray line: 1:1 rel.)
  - Caution: small value for $r_{1,UV}$ may be just due to nondetection in continuum images



Insights into the Origin of LAHs

- **First detection of the UV 2nd component** (r < 40 pkpc) offers direct evidence for a contribution from **satellite SF**
  - Agree with recent simulation results (Byrohl+20, Mitchell+20, Lake+15)
  - Can be tested with JWST by seeing if "Hα halos" exist or not
- To determine the origin of LAH at larger radii, deeper obs. & comparison with simulations are needed
  - Precise behavior of $r_{2,\mathrm{Ly}\alpha}$ and $r_{2,\mathrm{UV}}$ must be derived both from obs & sim
  - Predictions for cold stream contribution vary a lot

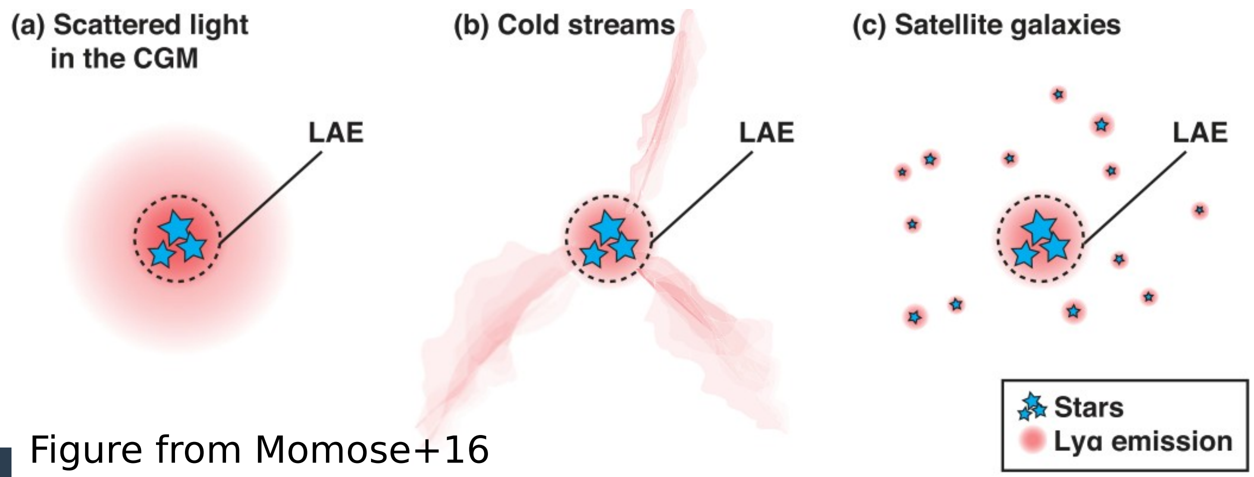
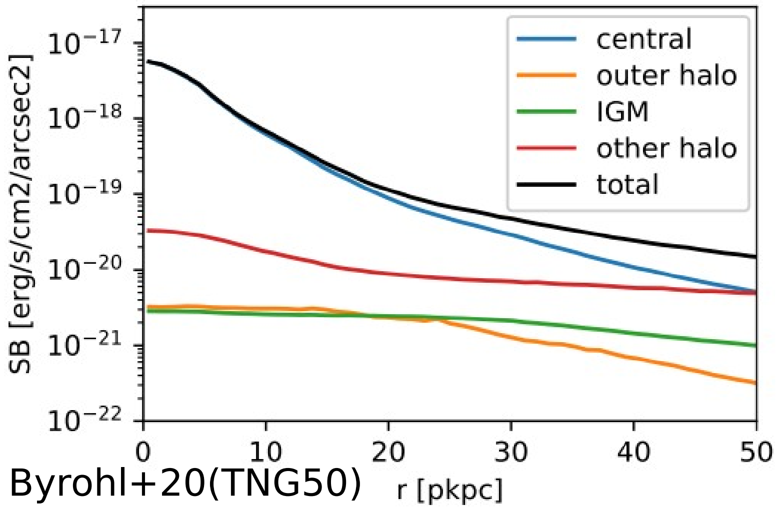


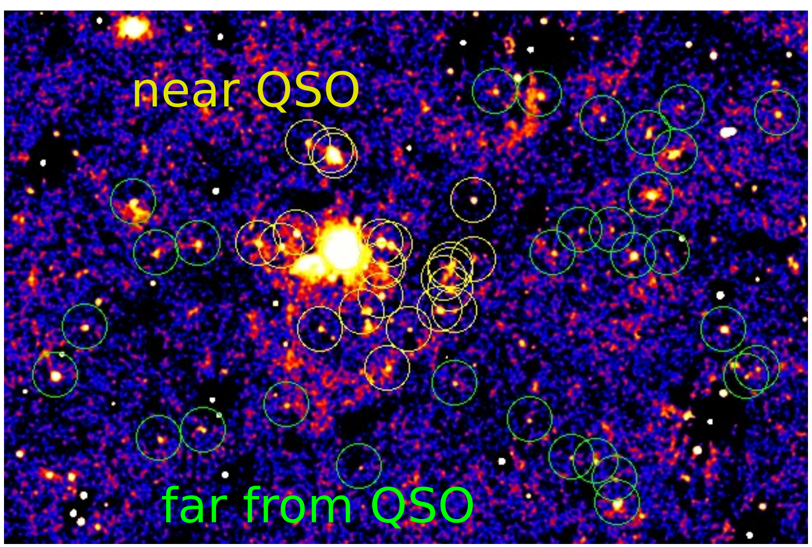
Figure from Momose+16



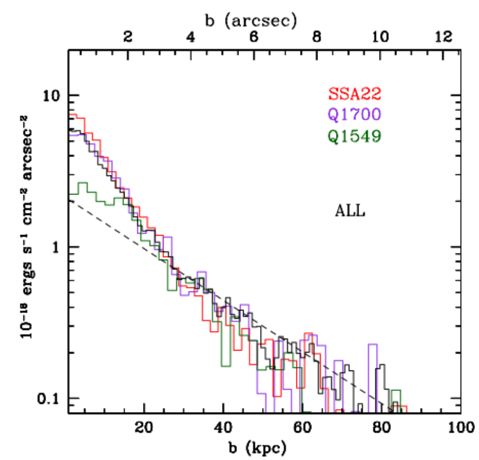
Byrohl+20(TNG50)

Origin of the Large LAH in PCs

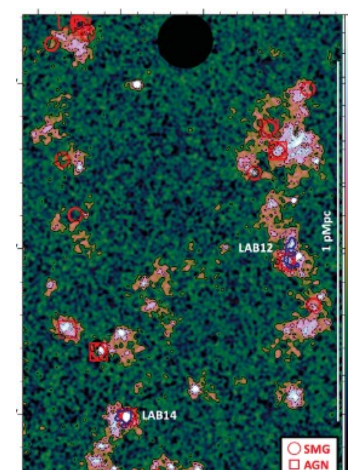
- Overlapping of galaxies or UV brightness of the PC LAEs cannot fully explain the large LAH
- We further divide the PC sample into near/far from the QSO sample
  - Far sample no longer has a very large LAH
  - Near sample shows an even larger LAH
- **Diffuse emission around the PC core may be the cause**



Steidel+11: SSA22, HS1700, HS1549



Umehata+19: SSA22



Take home message about LAH

- Sensitivity close to 1e-20 erg/s/cm^2/$arcsec^2$ is necessary for safe argument (at z~3) – **NB stacking with Subaru/HSC is still a powerful tool in the era of sensitive IFUs!**
- Lyα SB profiles are well fit with 2-component exponential functions
- **We found "UV halos"** around bright/low-EW LAEs
  - demonstrates **satellite SF** as important contributor
- $r_{1,Ly\alpha}$ and $r_{1,UV}$ correlate, but $r_{2,Ly\alpha}$ does not correlate with any photometric property – insufficient S/N?
- No dependence on large-scale environments **except for PCs**
  - very large LAHs may emerge in PCs at cosmic noon due to **diffuse Lyα emission from the structure**
- **Comments welcome! Slack or email** kikutast@ccs.tsukuba.ac.jp