Diffuse Lyα halos around galaxies at $z > 6$

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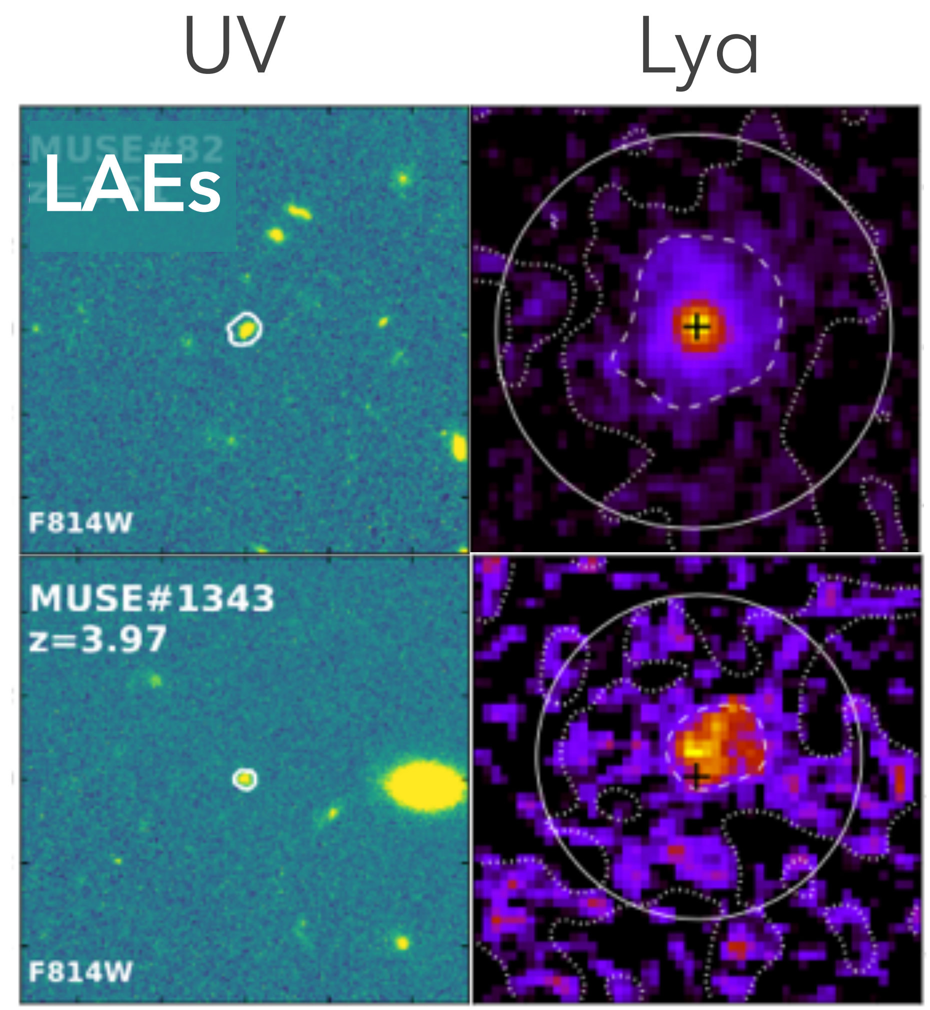
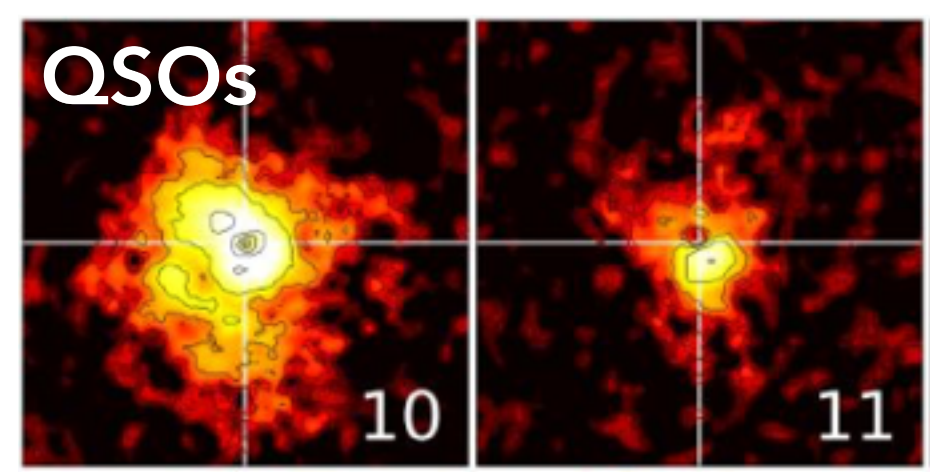
Lya halos as a tracer of the CGM

- Lya halo/nebular
  - Spatially extended feature in Lya emission around galaxies
  - Very diffuse (more than 2x faint)
  - Investigated mainly around LAEs, LBGs and QSOs

- What we should clarify?
  - Origin, Evolution, Relation with hosting galaxies

- Investigation for $z > 6$ Lya halos is crucial



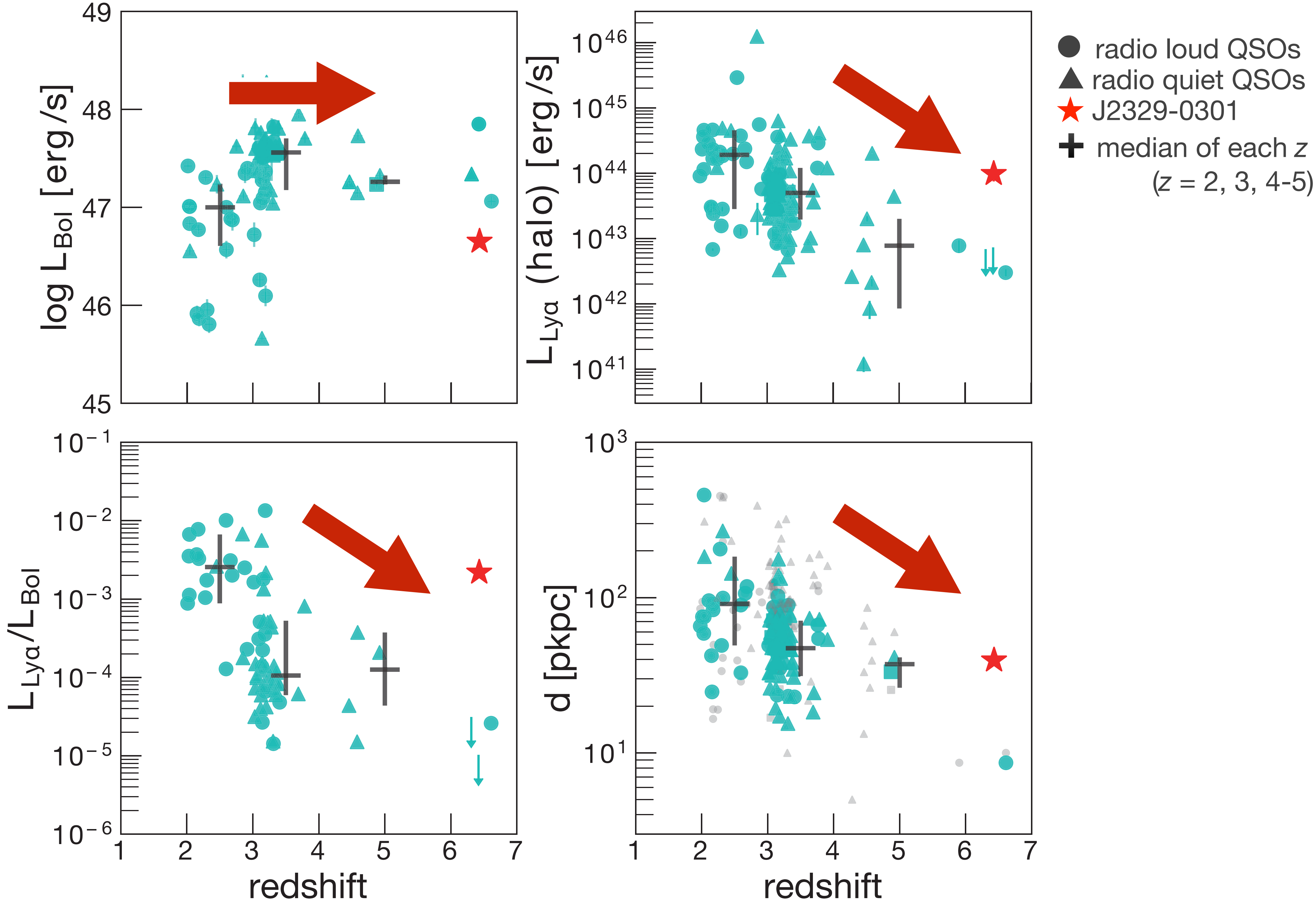


Steidel+11; RM+14; Tumlinson, Peeples & Werk 17; Lecqlarc+17; Arrigoni Battaia+19

4 Reasons Why at z > 6

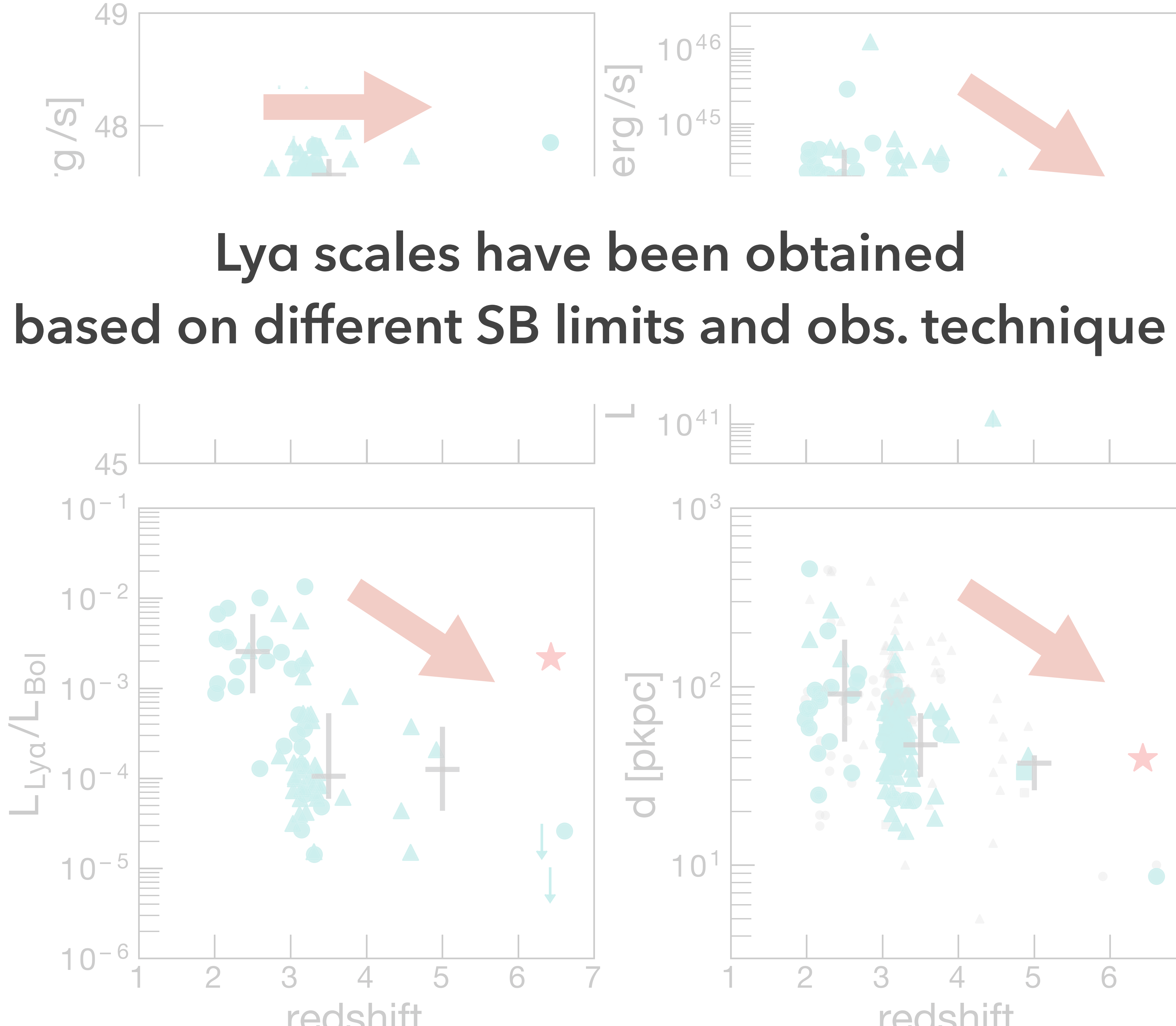
1. (QSOs) To examine he redshift evolution of QSOs' Lyα halos
2. (QSOs) To assess the possible correlation between QSOs' evolutional phase indicators and Lyα halo scales
3. (LAEs) To verify the possible size increase of Lyα halos

(QSOs) Redshift evolution from the compilation sample



RM+19 and reference there in

(QSOs) Redshift evolution from the compilation sample



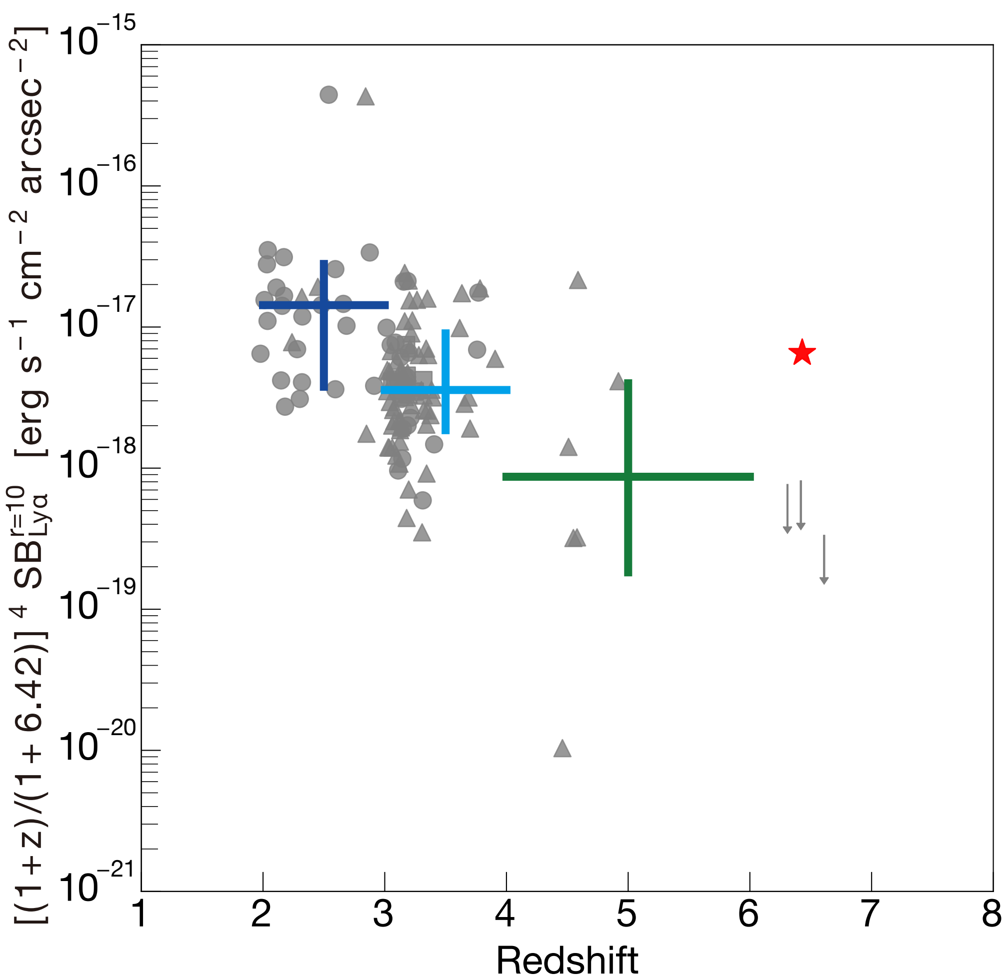
- ● radio loud QSOs
- ▲ radio quiet QSOs
- ★ J2329-0301
- ✚ median of each *z* (z = 2, 3, 4-5)

Lya scales have been obtained based on different SB limits and obs. technique

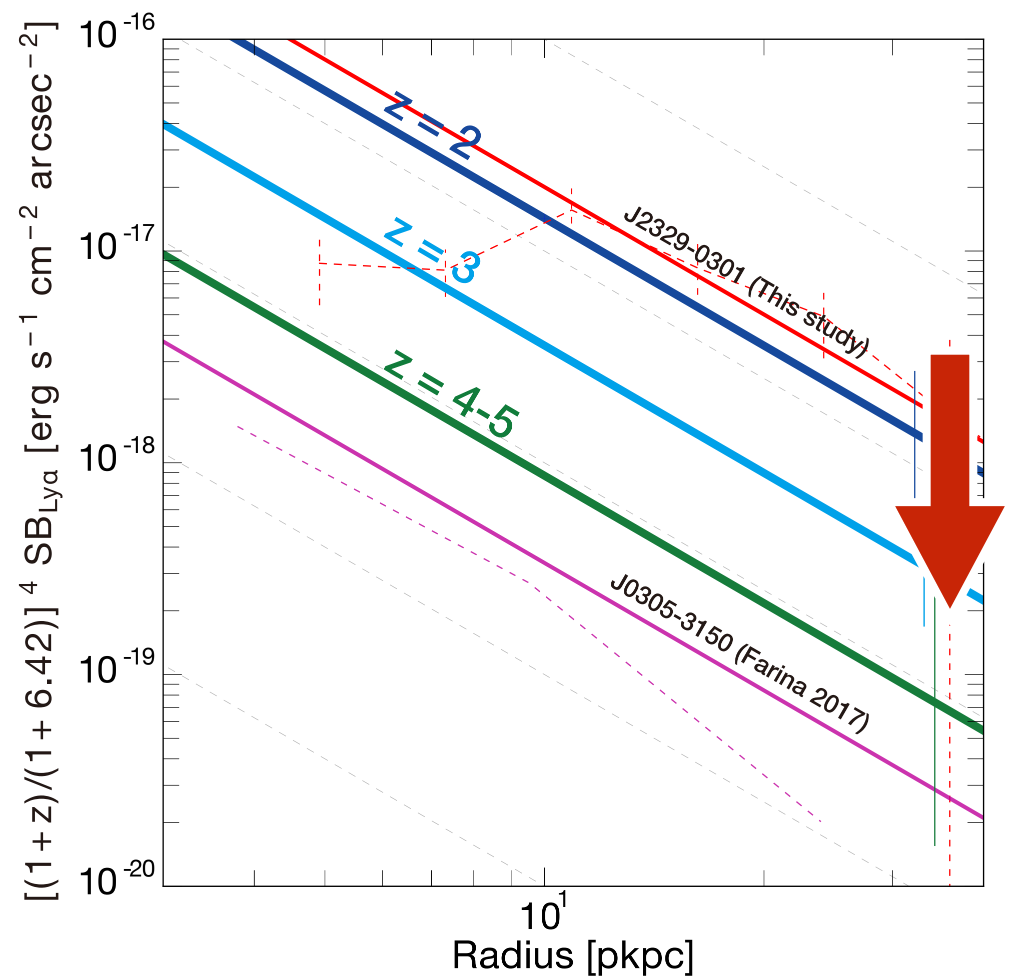
RM+19 and reference there in

Redshift evolution of surface brightness over 2 < z < 5

- Evaluate SB profile
  - Assumption
    1) $\underline{r_{\rm inner\_most} = 10\ \rm kpc}$
    2) $\underline{SB \propto r^{-2}}$ (-1.5 ~ -1.9 at z ~3)
  - Derive SB at 10 kpc ($SB_{\rm Ly\alpha}^{r=10}$)
  - $L_{\rm Ly\alpha} \propto (1+z)^4\ r^{-2}$ SB



- SB profile at each redshift
  - Adopt the median of $SB_{\rm Ly\alpha}^{r=10}$
  - Plot SB profile



RM+19 and reference there in

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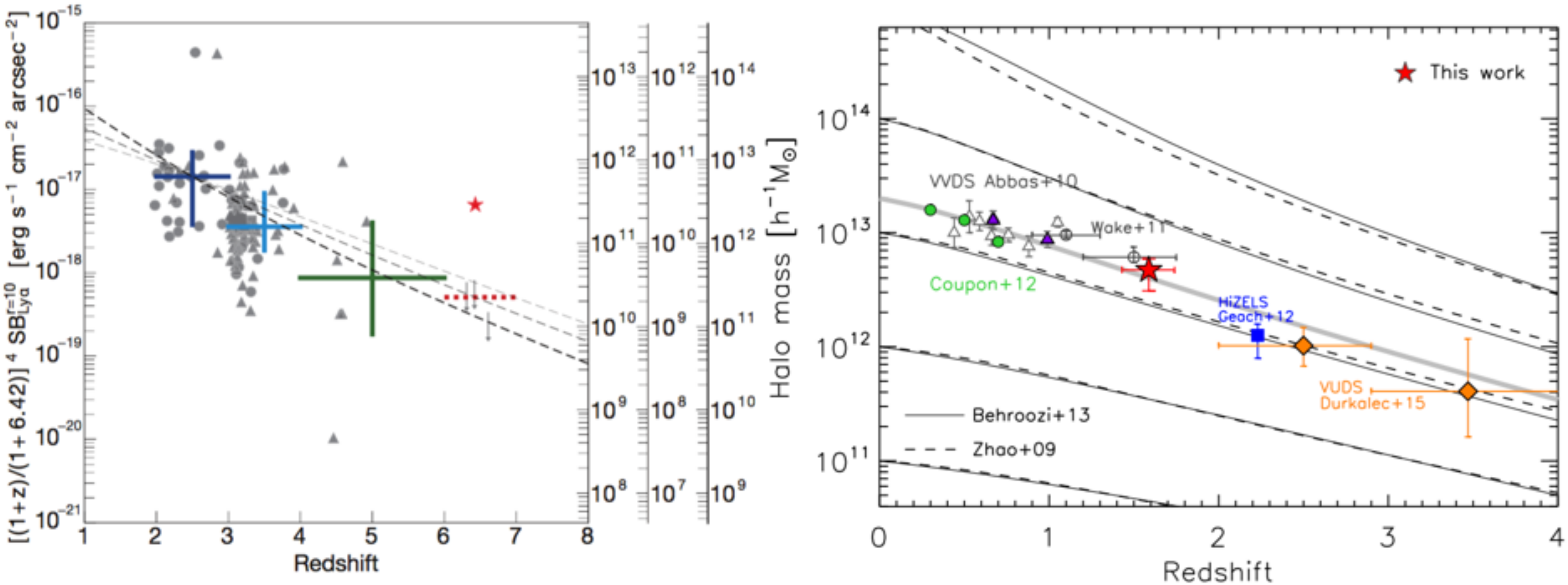

- If Lyα halos are attributed to fluorescent light from optically thin CGM, an SB of Lyα halos can be described by
    - $SB_{Ly\alpha} \propto n_H * N_H * f_c \sim \propto$ total gas mass of the CGM

The CGM grows in mass keeping pace with hosting DHs

Kashino+17; RM+19 and reference there in

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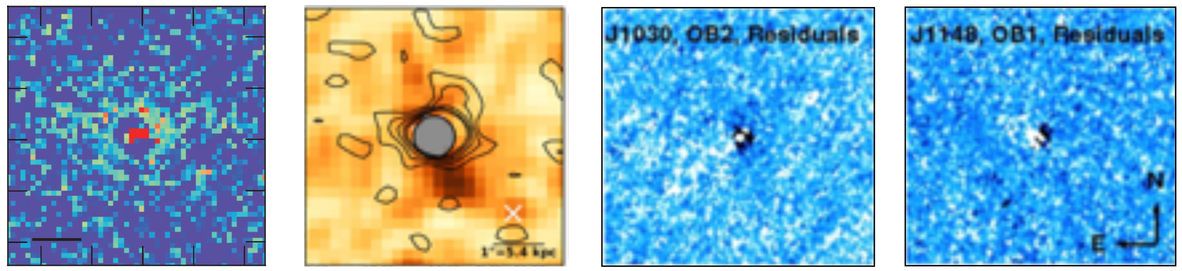
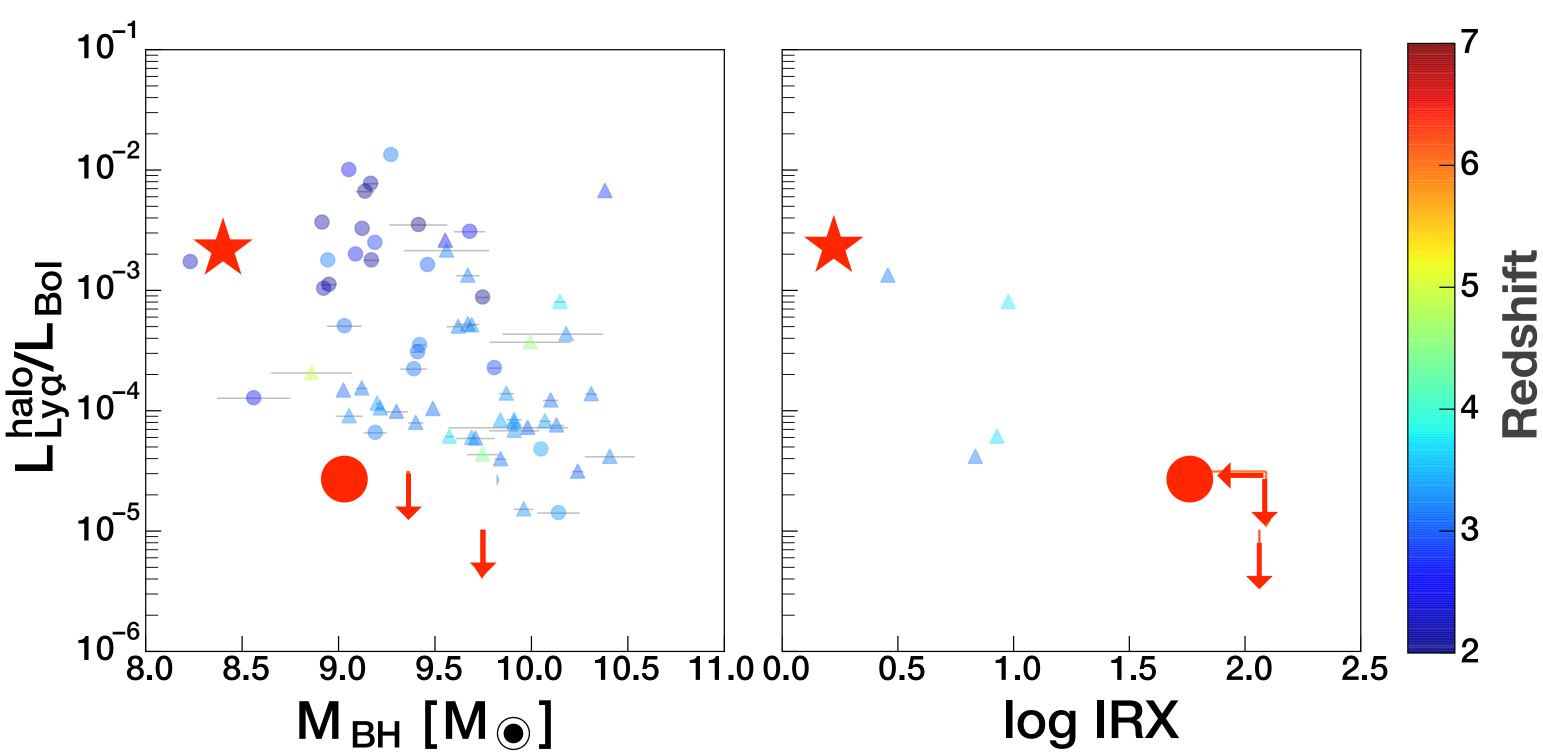
(QSOs) Correlations between Lya halos and several parameters



Investigate correlations among 4 QSOs at z > 6

	★ J2329−0301	● J0305−3150	↓ J1030+0524	↓ J1148+5251
Lyα halo	detection	detection	non-detection	non-detection
$\log M_{BH}$ [$M_\odot$]	8.40	8.98 – 9.08	9.00 – 9.56	9.75
$\log L_{Bol}$ [erg s^{-1}]	46.60	47.06	47.37	47.85
Eddington ratio	1.3	0.68 – 0.74	0.50	1.01
SFR [$M_\odot$ yr^{-1}]	13	545	< 3165	3801 – 6000
$\log L_{IR}$ [$L_\odot$]	10.95	12.83	< 13.53	13.74
$\log M_{dust}$ [$M_\odot$]	< 7.00	8.65 – 9.38	< 8.63	8.85



- ✳ M_{BH}
  - J2329 has the least M_{BH}
  - Possible anti-correlation between L_{Lya} and M_{BH}
- ✳ L_{IR} or IRX (= L_{IR} / L_{UV})
  - J2329 shows the faintest in L_{IR}
  - Possible anti-correlation between L_{Lya} and IRX

Decarli+12; Farina+17; RM+19

Lyα halos with QSOs age

A luminous (and large) Lyα halo likely exists around QSOs with a small M_{BH} and IRX

M_{BH} can be referred to a QSO's age
$M_{BH} \propto \exp(t)$

+

Coevolution of an SMBH
and its host galaxy

A luminous and large Lyα halo likely exists around QSOs in the young phase of their activity.

Young phase

M_{BH} ➡ increase

Mature phase

M_{BH} ➡ increase

L_{IR}, IRX ➡ increase

Old phase

e.g., Mogorrian+98; Merritt & Ferrarse 01; McLure & Dunlop 02; Graham & Scott 13; Kormendy & Ho 13

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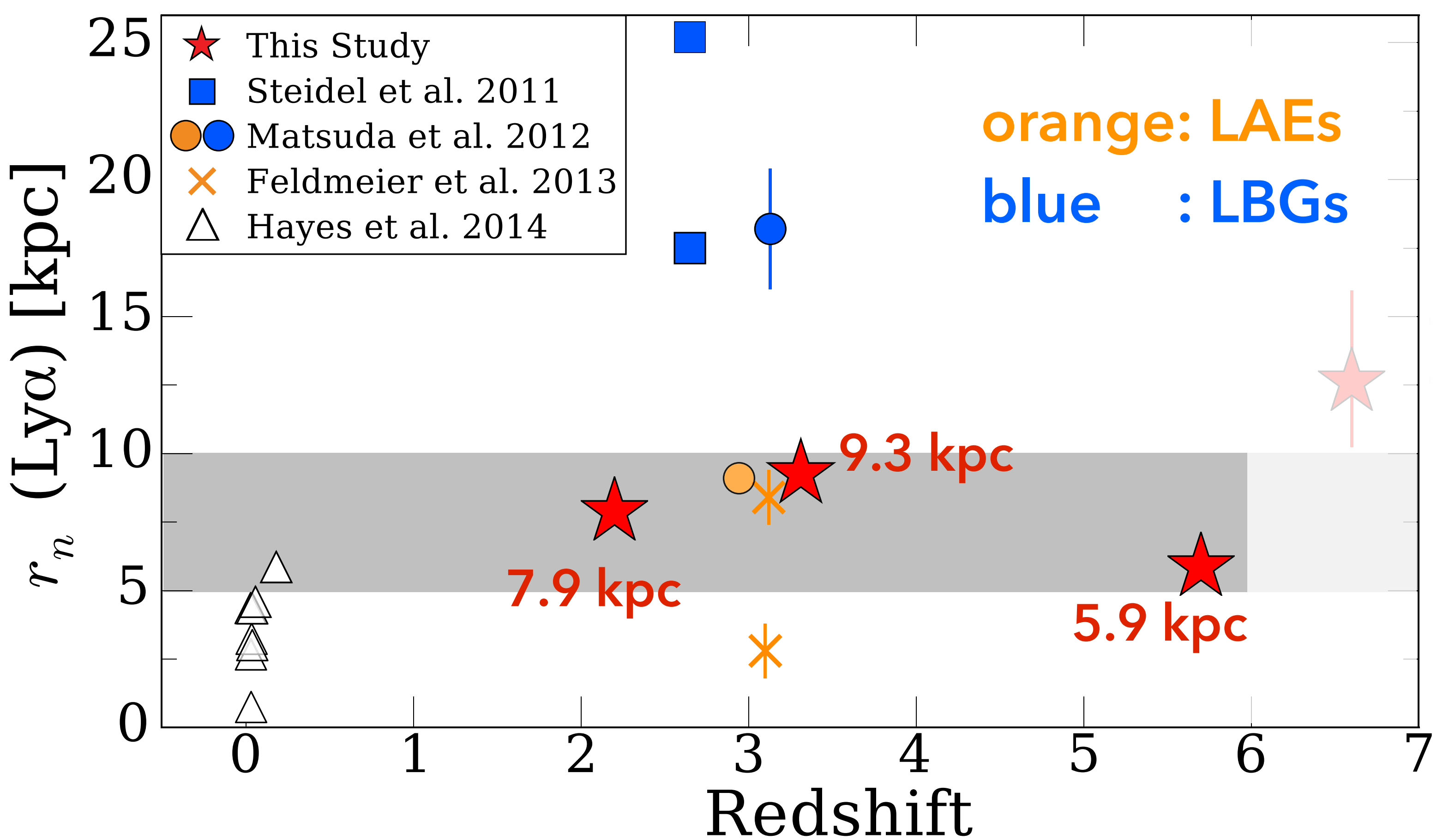
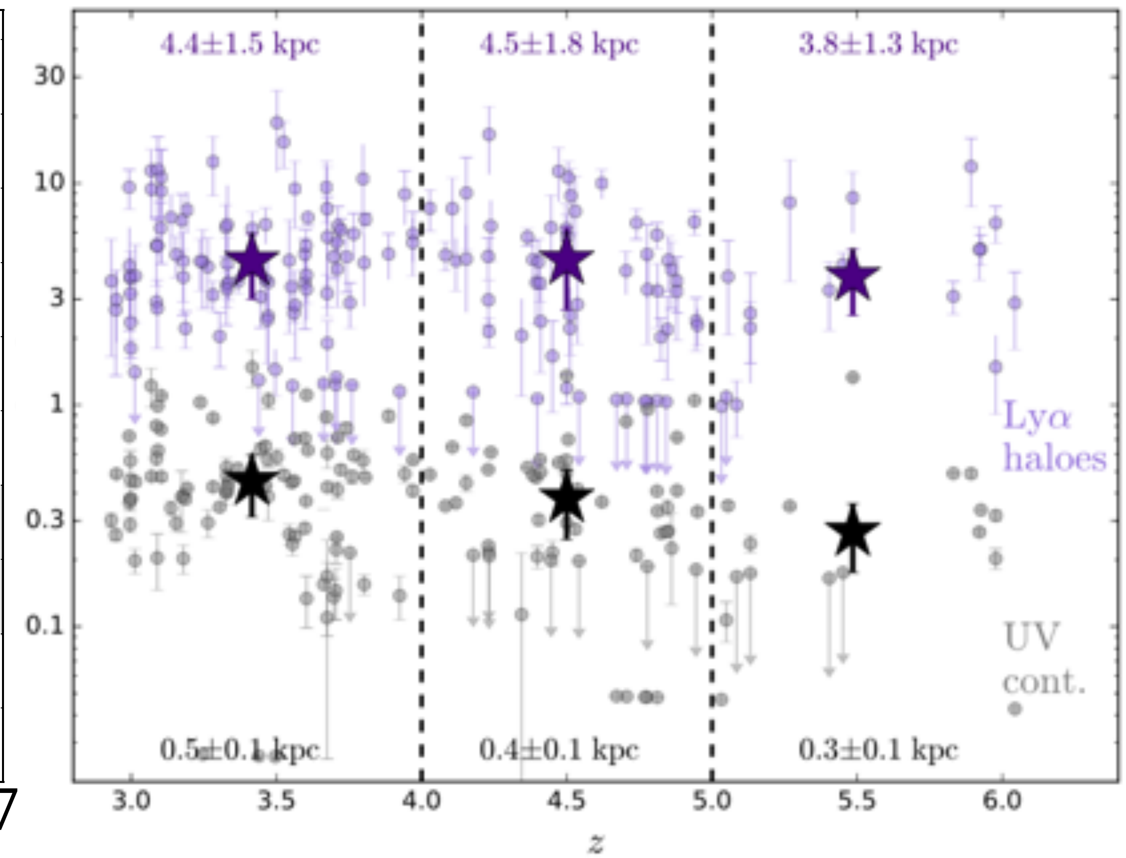
(LAEs) Redshift evolution of Lya halos

- At $2 < z < 6$
  - no evolution (r_s = 5–10 kpc)

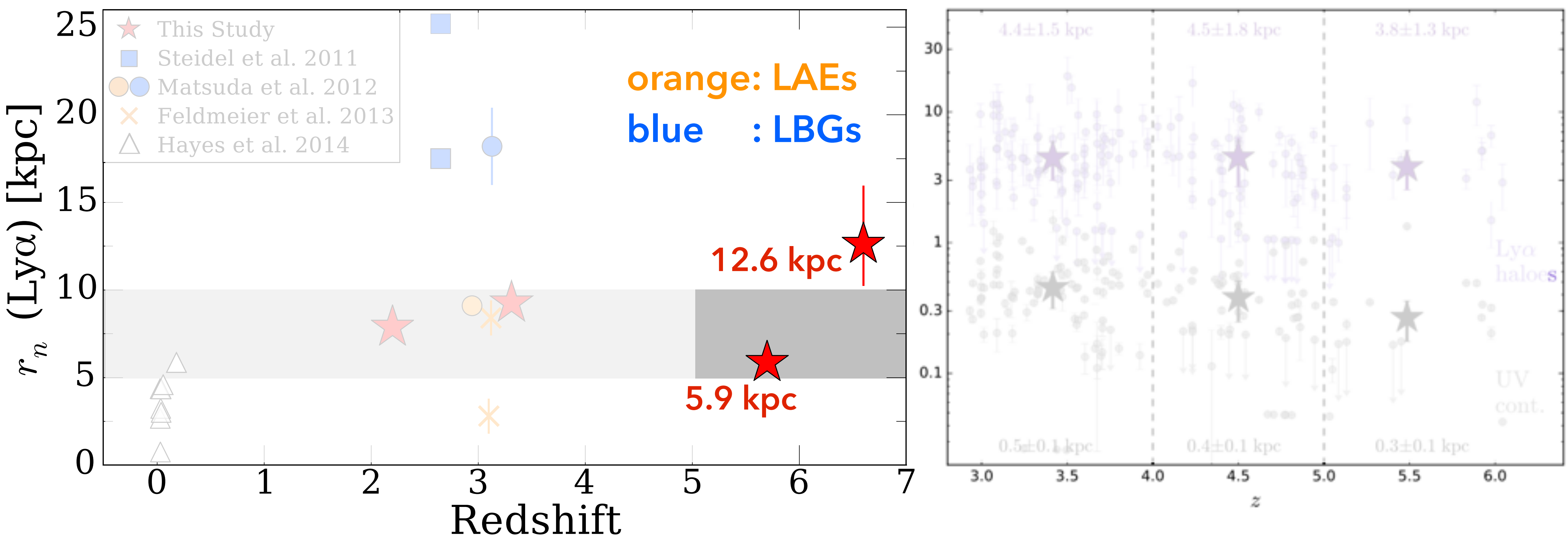




RM+14; Wisotzki+16; Leclercq+17

Redshift evolution of Lyα halos

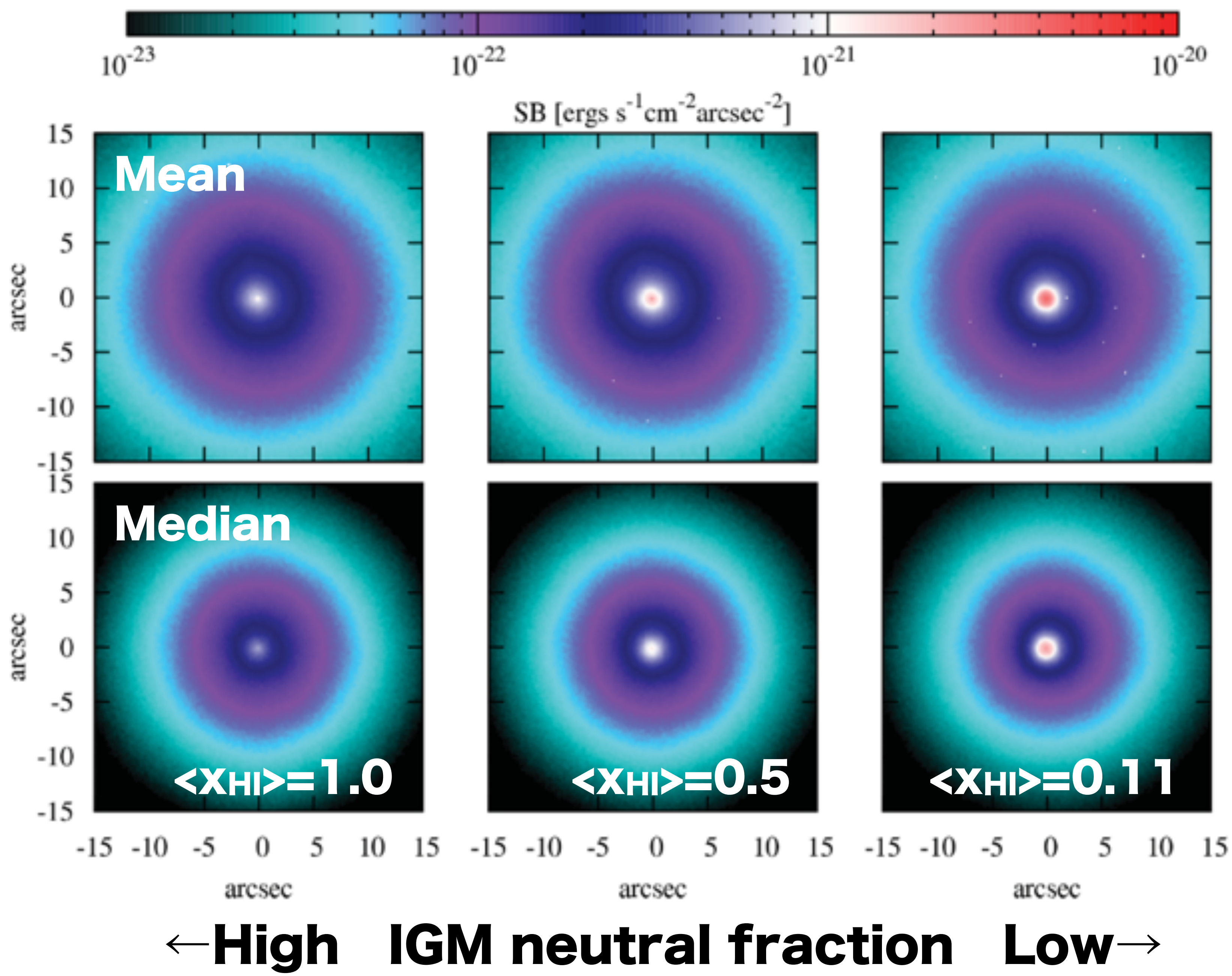
- At 5 < z < 6
  - possible increase (~ 2σ level significance)



The size increase is likely due to the cosmic reionization

RM+14; Wisotzki+16; Leclercq+17

Redshift evolution of Lya halos



Shape of SB profile

$\langle x_{HI} \rangle$ small → compact

$\langle x_{HI} \rangle$ large → extend

Possible increase may be due to the increase of x_{HI}

Jeeson-Daniel+12

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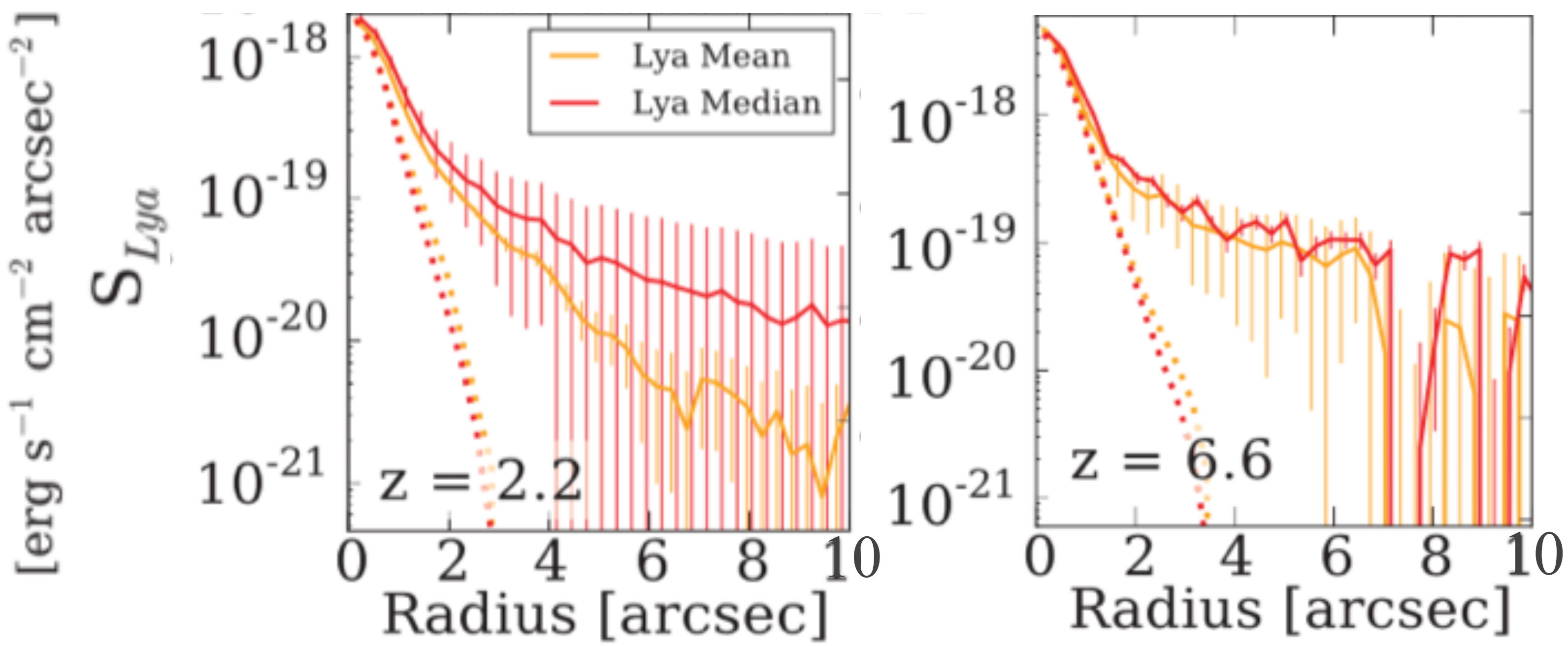
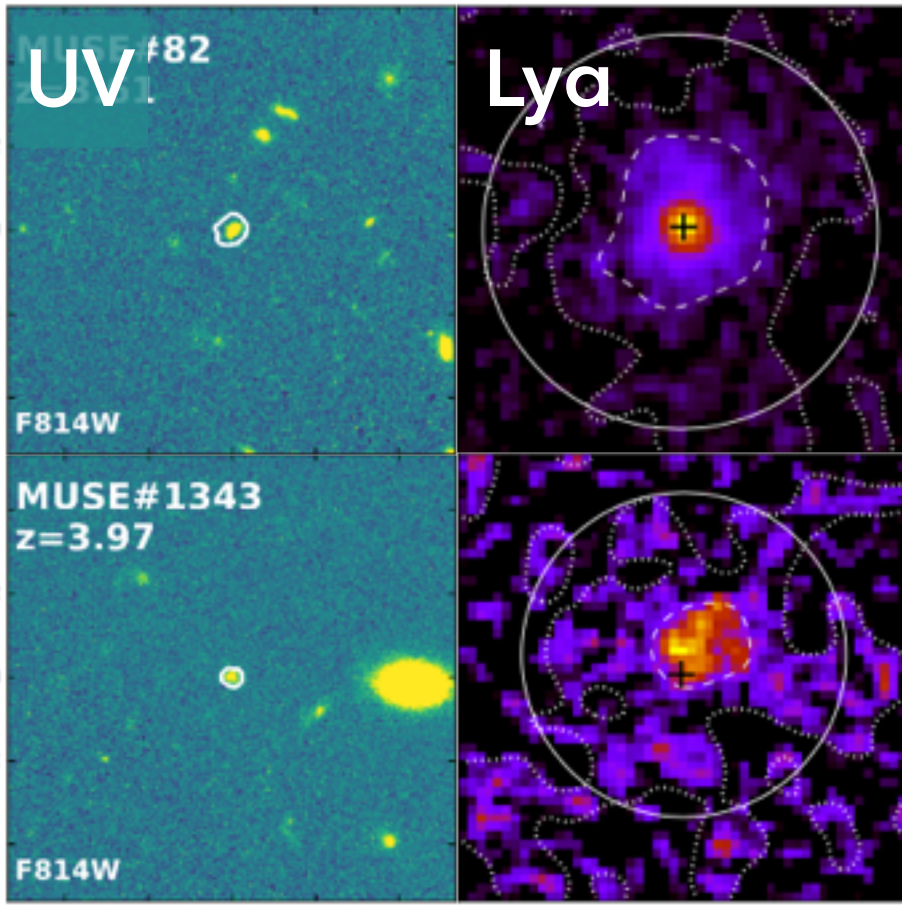
Lya halos are generally faint...



- Faint...
  - 2-10 times fainter than the center

sub \ z	2.2	3.1	5.7	6.6
other works	92 @z~2.7 (Steidel+2011)	22 (Hayashino+2004)	43 (Jiang+2013)	40 (Jiang+2013)
	187 (Feldmeier+2013)	241, 179 (Feldmeier+2013)		
		> 2000 (Matsuda+2012)		
MR14	3665	316	397	119

Lya halos are generally faint, but…



- Faint, but…
  - IFU enables to detect Lya halos within a relatively short time (several hours).

Lecqlarc+17

Before MUSE				After MUSE	
2004-	2007-	2010-	2013-	2016-	2019-
Hayashino+04	Rauch+08	Steidel+11 Matsuda+12	Jiang+13 Feldmeier+13 Hayes+13, 14 Momose+14	Wisotzki+16 Patrício+16 Momose+16 Rauch+16 Xue+17 Leclercq+17	

Advantage of FOCAS IFU on Subaru

- FOCAS IFU will reach the same SB limit which was achieved by S-Cam 6 hours on-source obs., within ~ 20 min. (!!!)

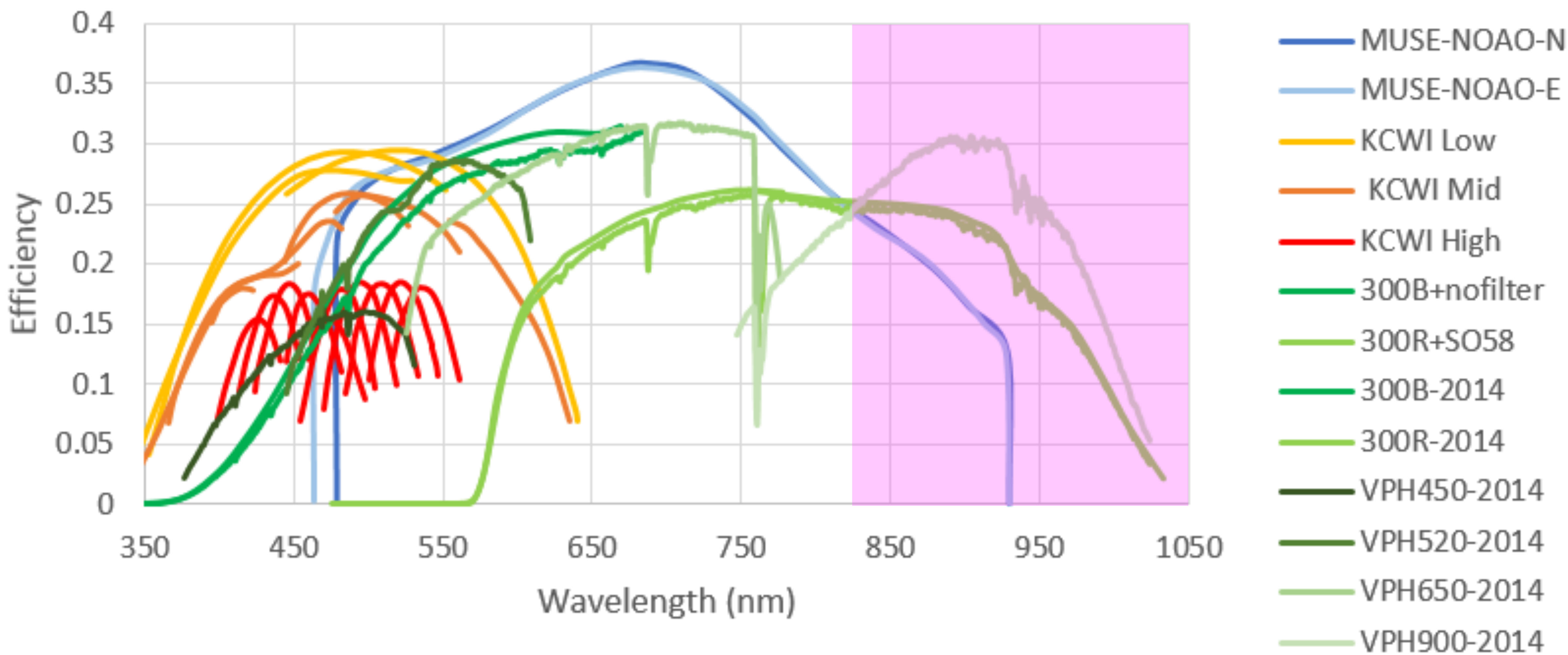


Fig. by Ozaki-san

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4. Higher observational efficiency at $\lambda_{obs} \geqq 8500$ Å by FOCAS IFU on Subaru