LAEs and LBGs at z=3-6 in Cosmological SPH Simulations

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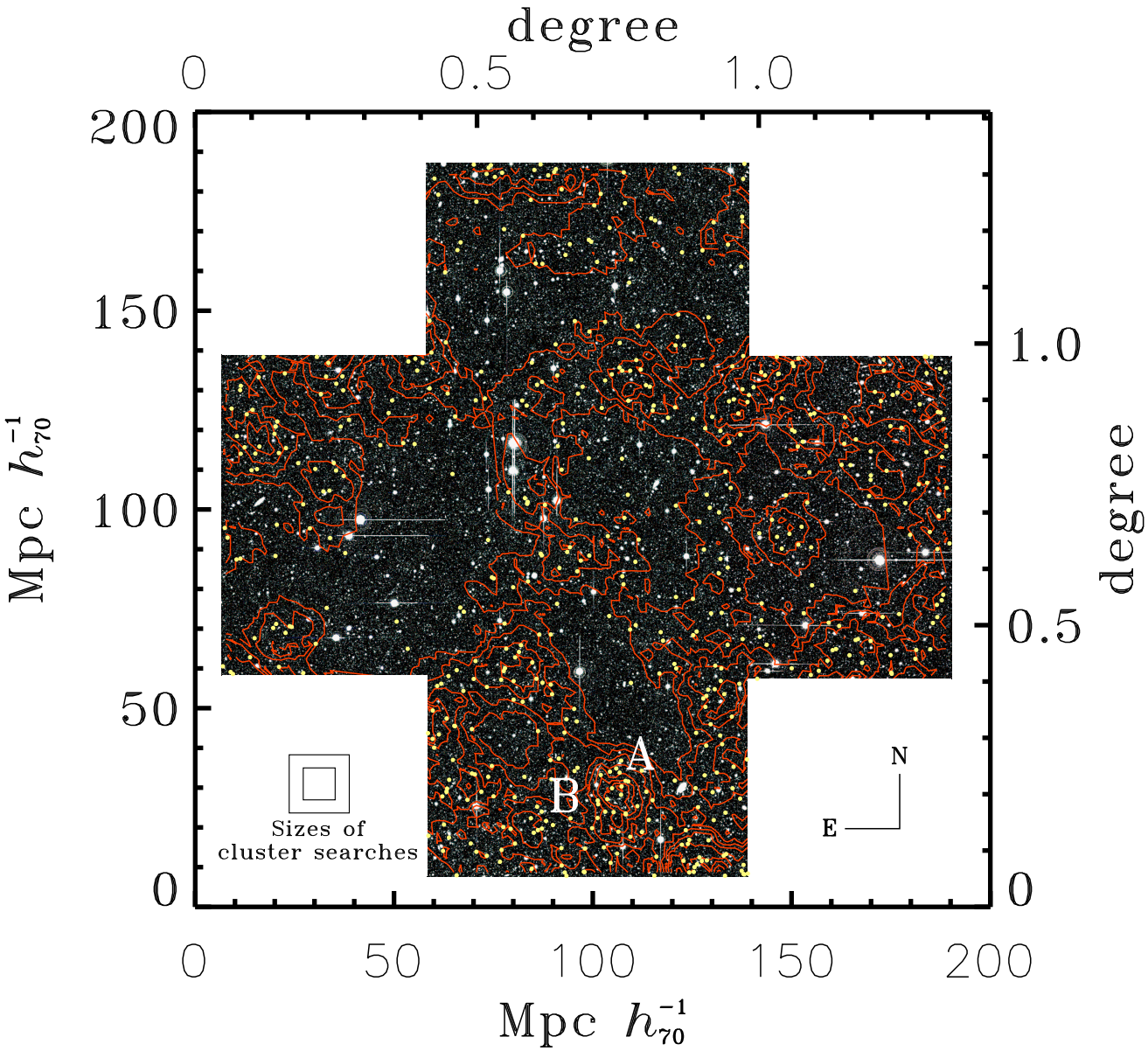
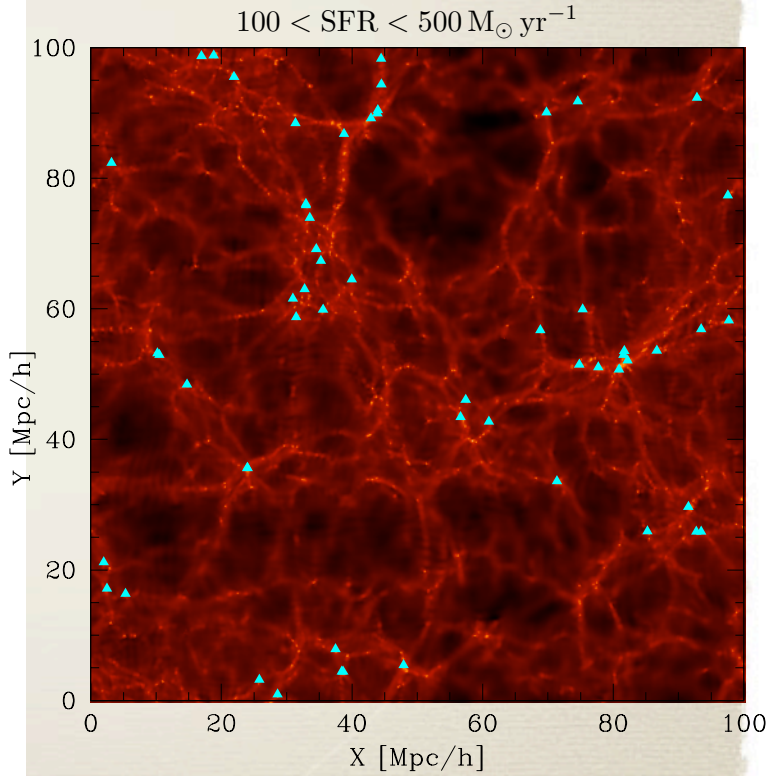
Large-scale structure traced by LAEs at z~6





Ouchi+ '05

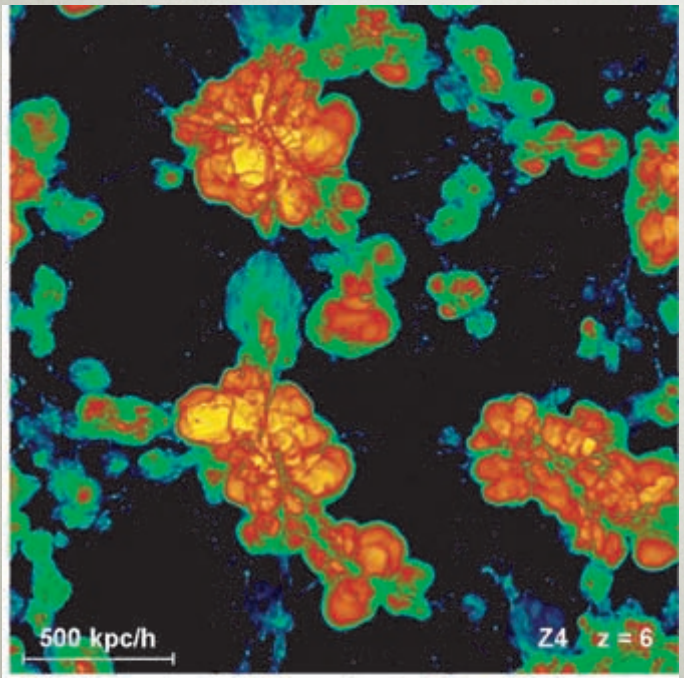
SXDS, 515 LAEs

Cosmological Hydrodynamic Simulations

- model galaxy formation from first principles in a ΛCDM universe
- GADGET2 Smoothed Particle Hydrodynamics code (Springel '05)

radiative cooling/heating, star formation, SN & galactic wind feedback

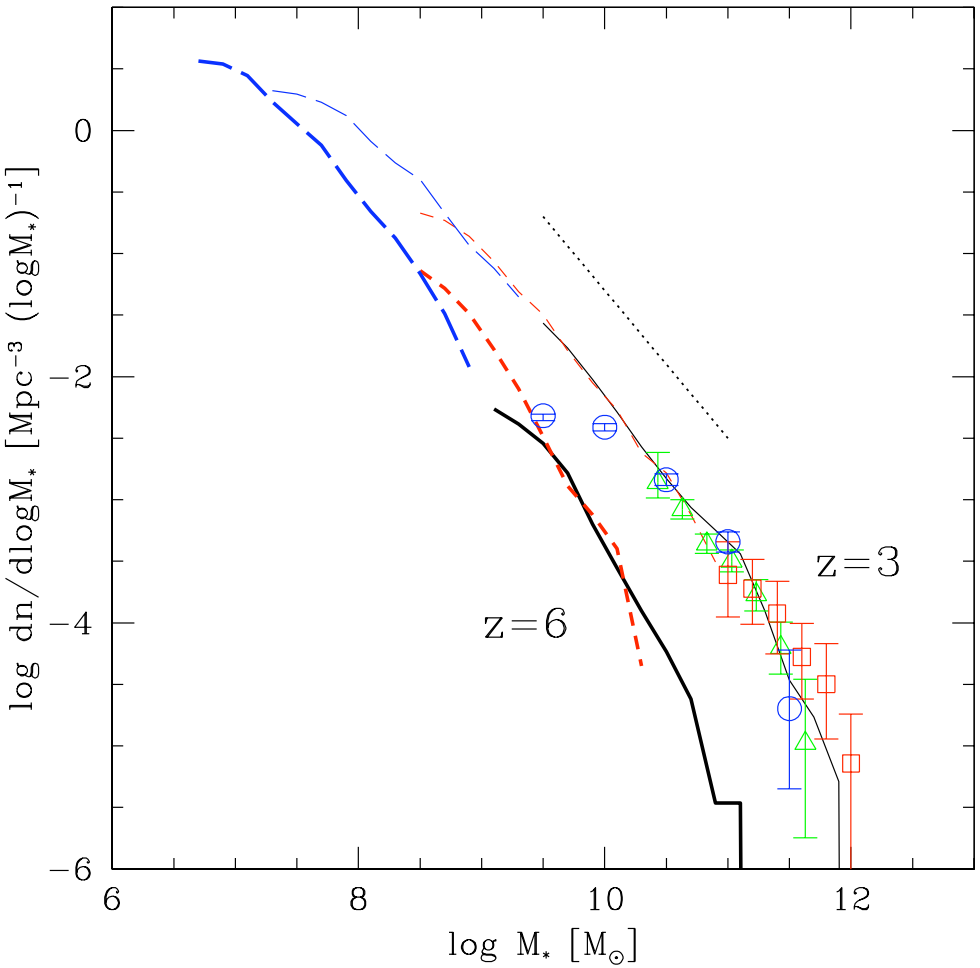
- LBGs@z=3–6, massive gal@z=1–2, DLAs, ... (KN+ 04ab, 05ab)



Box size	$N_{\rm p}$	$m_{\rm DM}$	$m_{\rm gas}$	ϵ	$z_{\rm end}$	Wind
10.00	2×144^3	2.42×10^7	3.72×10^6	2.78	2.75	None
10.00	2×144^3	2.42×10^7	3.72×10^6	2.78	2.75	Weak
10.00	2×144^3	2.42×10^7	3.72×10^6	2.78	2.75	Strong
10.00	2×216^3	7.16×10^6	1.10×10^6	1.85	2.75	Strong
10.00	2×324^3	2.12×10^6	3.26×10^5	1.23	2.75	Strong
33.75	2×216^3	2.75×10^8	4.24×10^7	6.25	1.00	Strong
33.75	2×324^3	8.15×10^7	1.26×10^7	4.17	1.00	Strong
100.0	2×324^3	2.12×10^9	3.26×10^8	8.00	0.00	Strong
100.0	2×486^3	6.29×10^8	9.67×10^7	5.00	0.00	Strong
$[h^{-1}\mathrm{Mpc}]$		$[h^{-1}M_\odot]$			$[h^{-1}\mathrm{kpc}]$	

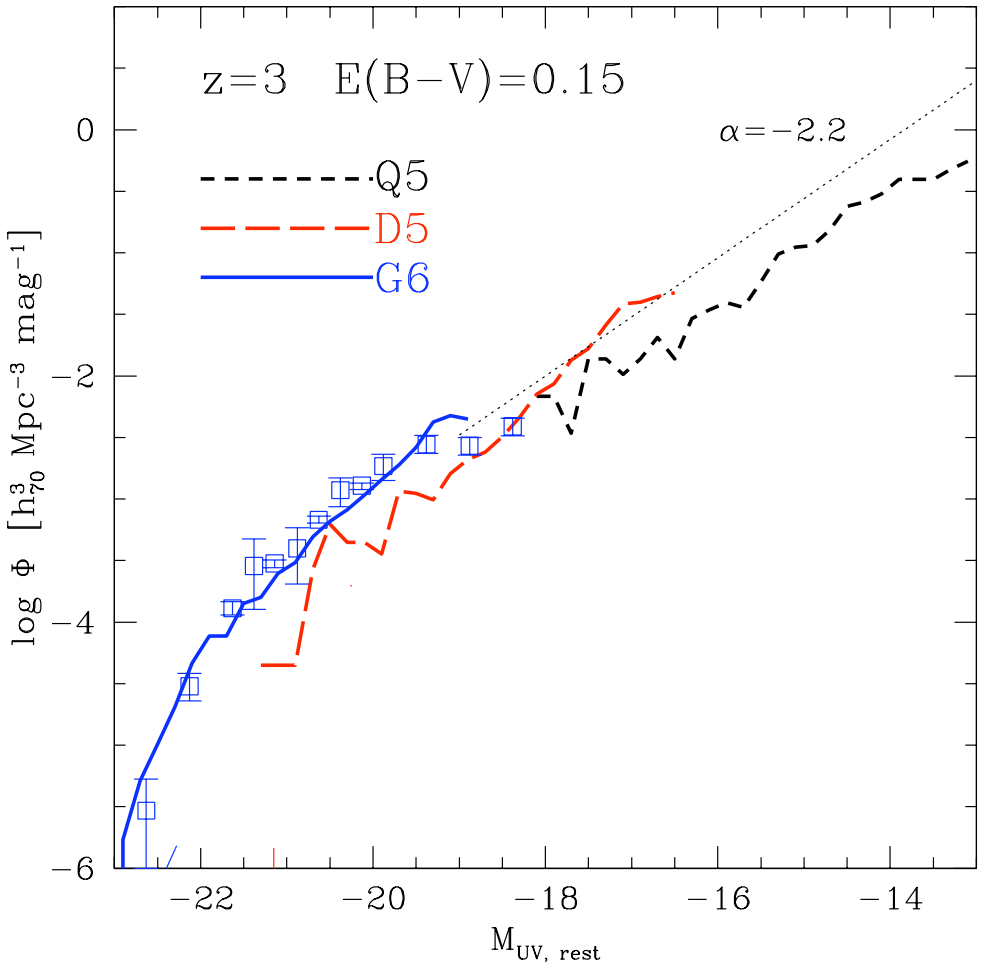
At z=3, things look good.

Galaxy Stellar Mass Function



Data: Drory+ '05
Fontana+ '06
Perez-Gonzalez+ '07

Rest-frame UV LF



Data: Adelberger & Steidel 00'

Lyα LF

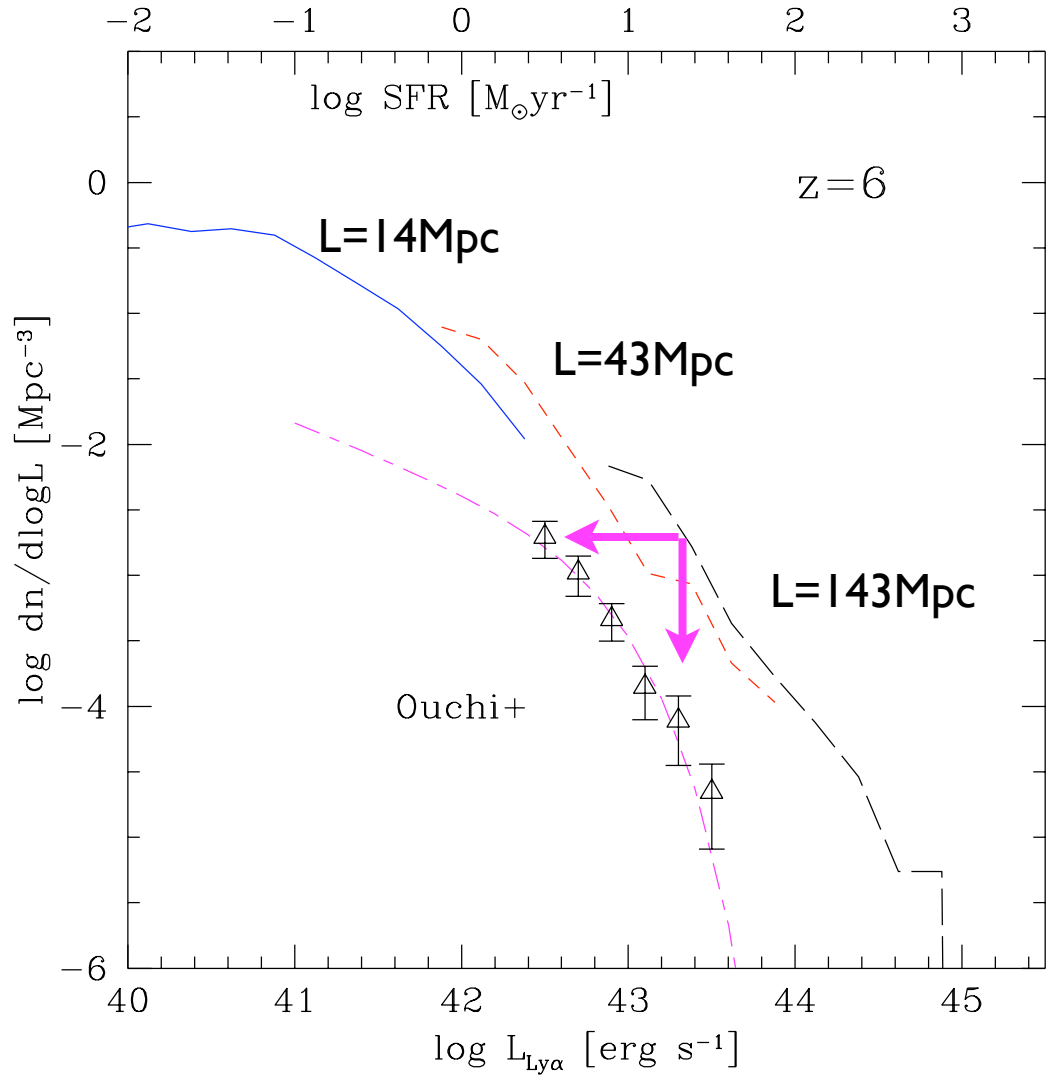
Assuming

$$\frac{L_{\mathrm{Ly}\alpha}}{10^{42}\mathrm{erg\,s^{-1}}} = \frac{\mathrm{SFR}}{1 M_\odot\,\mathrm{yr}^{-1}}$$

(Cowie & Hu '98; Leitherer+ '99)

Salpeter IMF, [0, 100]$M_\odot$,
$0.05<Z/Z_\odot<2$

- Without any corrections, simulation overpredicts the Lyα LF by x5-13



Two simple scenarios

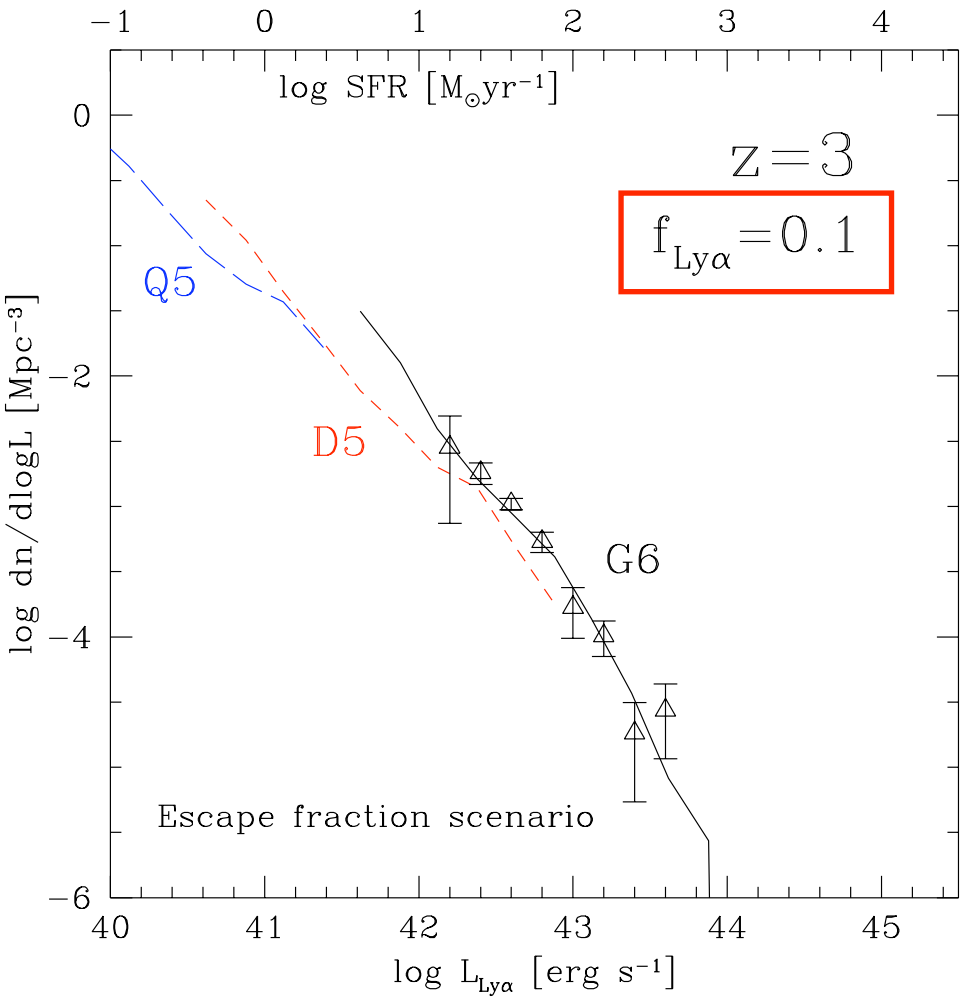
- **"Escape fraction" scenario:**
  - all LBGs emit Lyα emission, but uniformly attenuated by a factor of **$f_{Ly\alpha}$**: $L_{\mathrm{Ly}\alpha}^{\mathrm{observed}} = f_{\mathrm{Ly}\alpha} L_{\mathrm{Ly}\alpha}^{\mathrm{sim}}$

$$f_{\mathrm{Ly}\alpha} = f_{\mathrm{dust}} \left(1 - f_{\mathrm{esc}}^{\mathrm{ion}}\right) f_{\mathrm{IGM}},$$

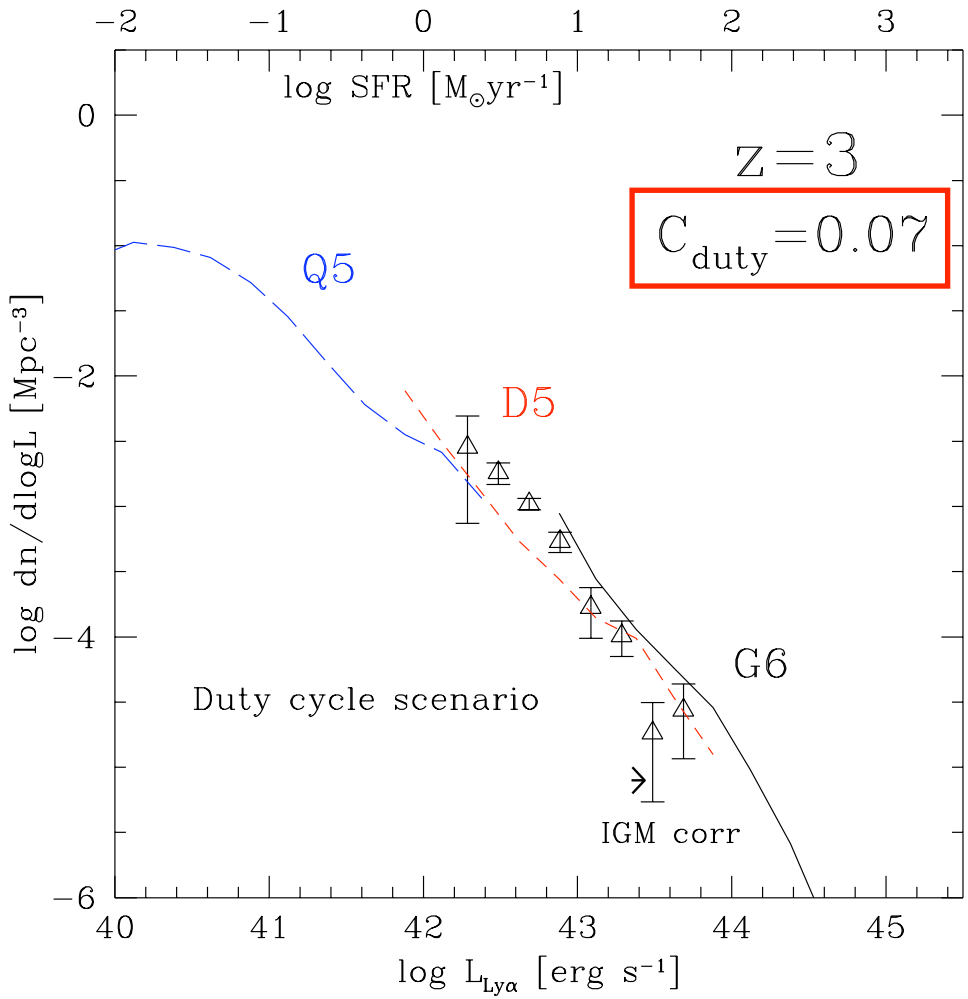
- **"Duty cycle" scenario:**
  - only a fraction **C_{duty}** of starforming gals are active as LAE

Lyα LF @ z=3

Escape fraction scenario



Duty cycle scenario

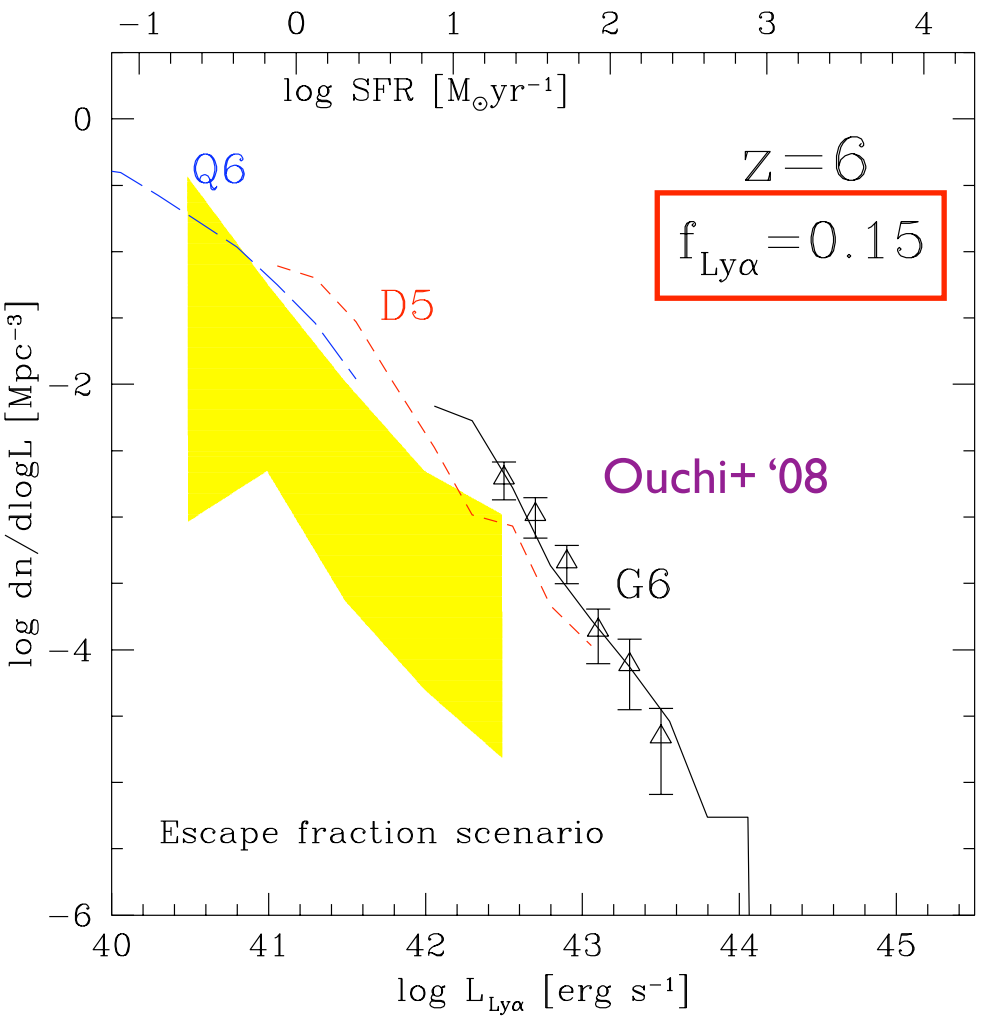


Data points: Ouchi+ '08

f_{IGM}=0.82 (Madau+ '95)

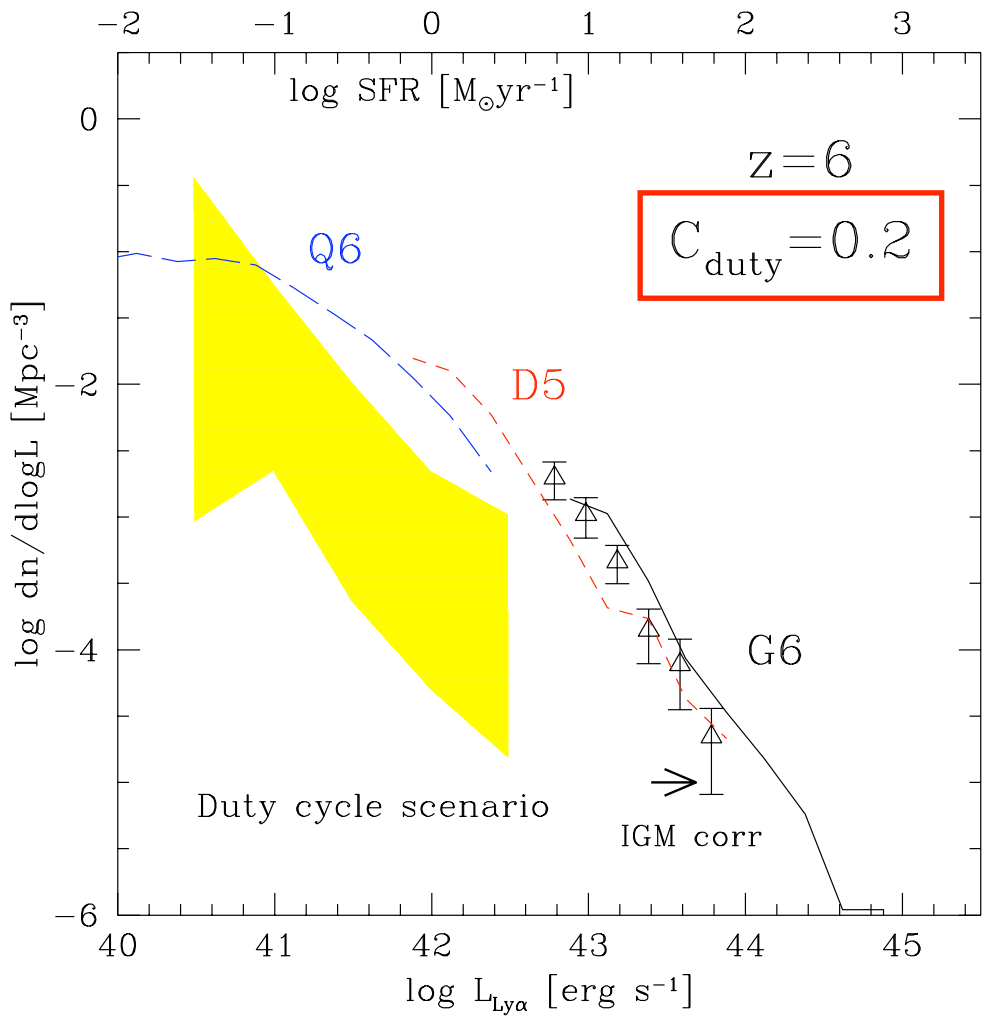
Lyα LF @ z=6

Escape fraction scenario



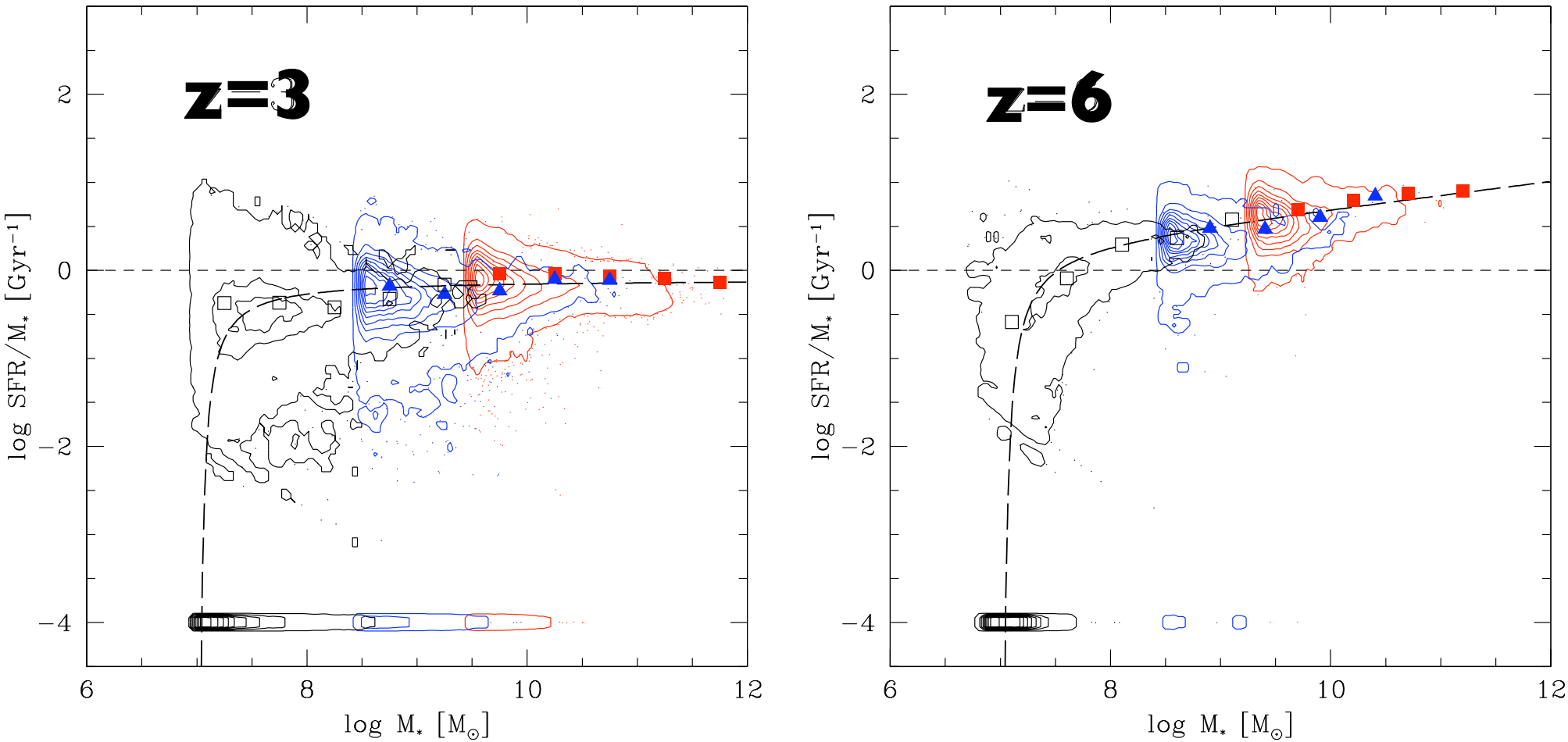
yellow shade: Santos+ '04

Duty cycle scenario



f_{IGM}=0.52 (Madau+ '95)

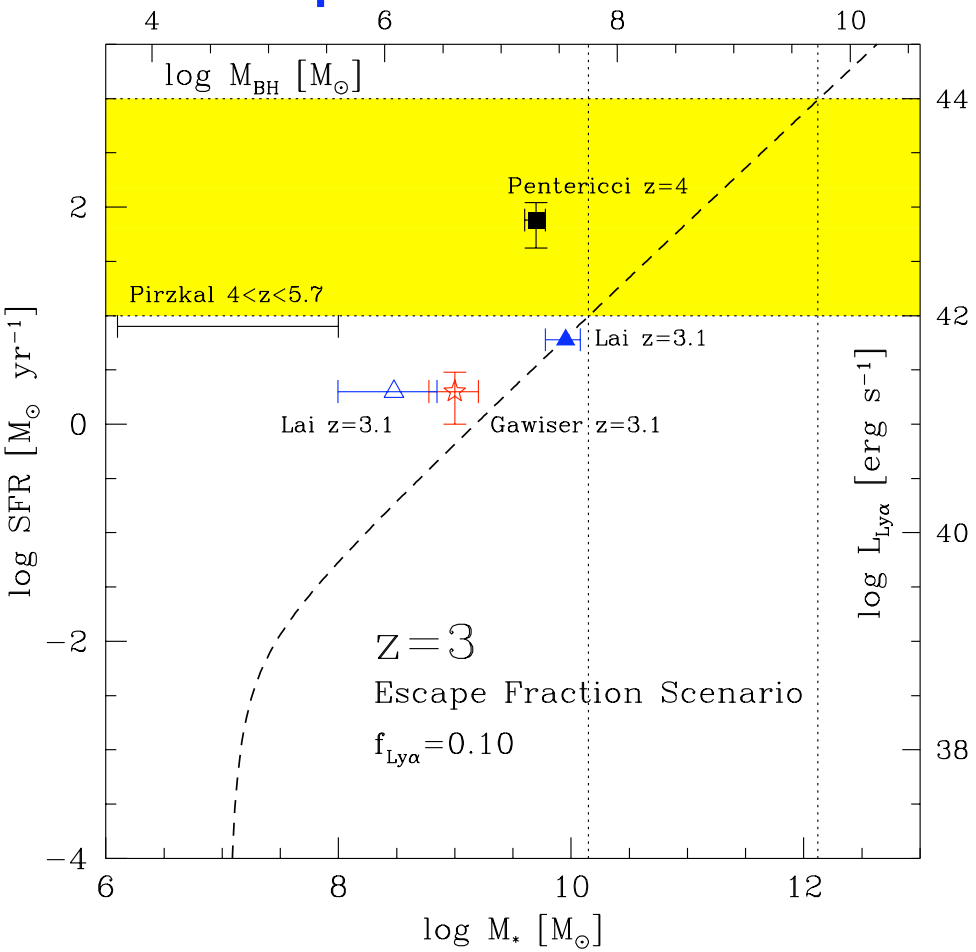
Specific SFR vs. M*



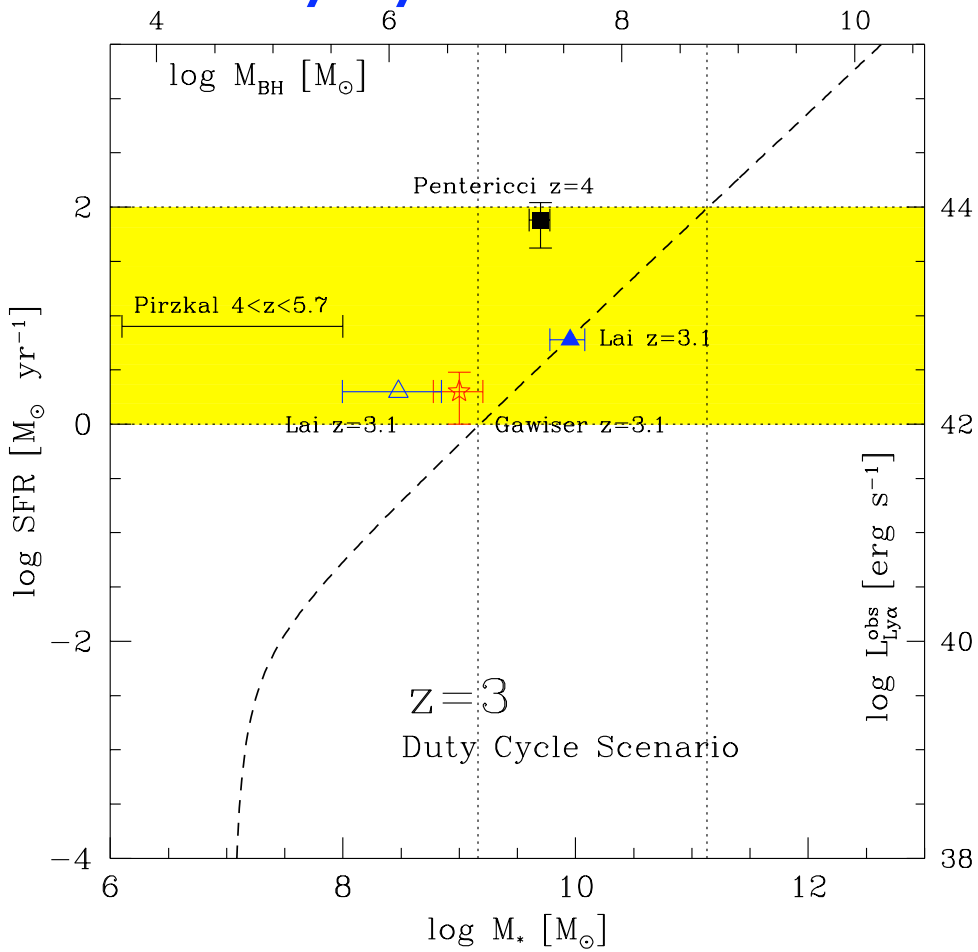
SF efficiency declines from z=6 to z=3.

M* vs. SFR @z=3

Escape fraction scenario



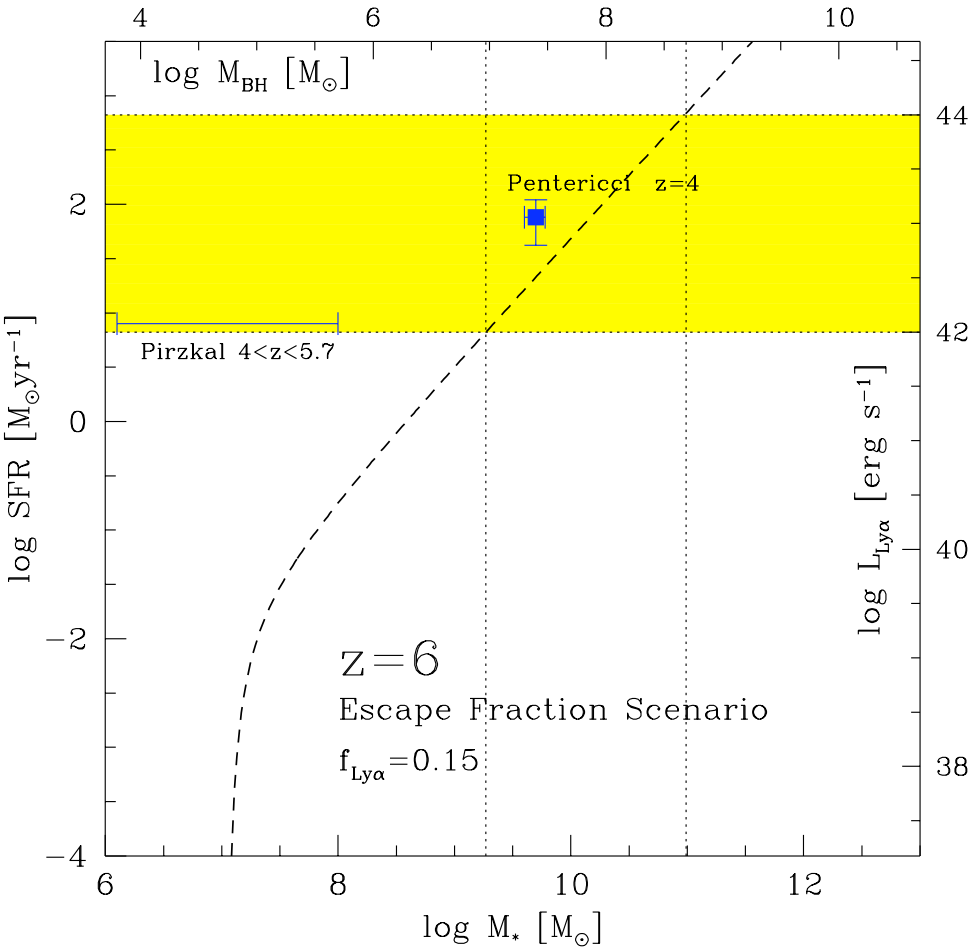
Duty cycle scenario



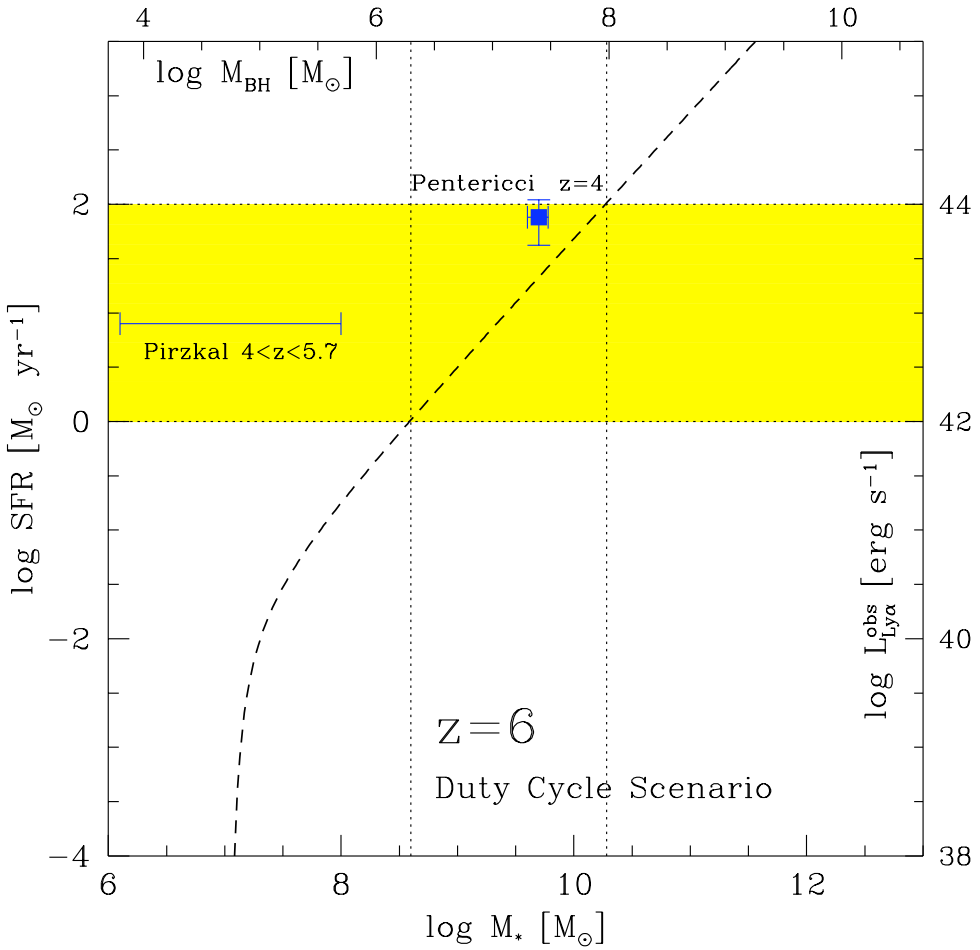
This comparison favors the Duty cycle scenario.

M* vs. SFR @z=6

Escape fraction scenario

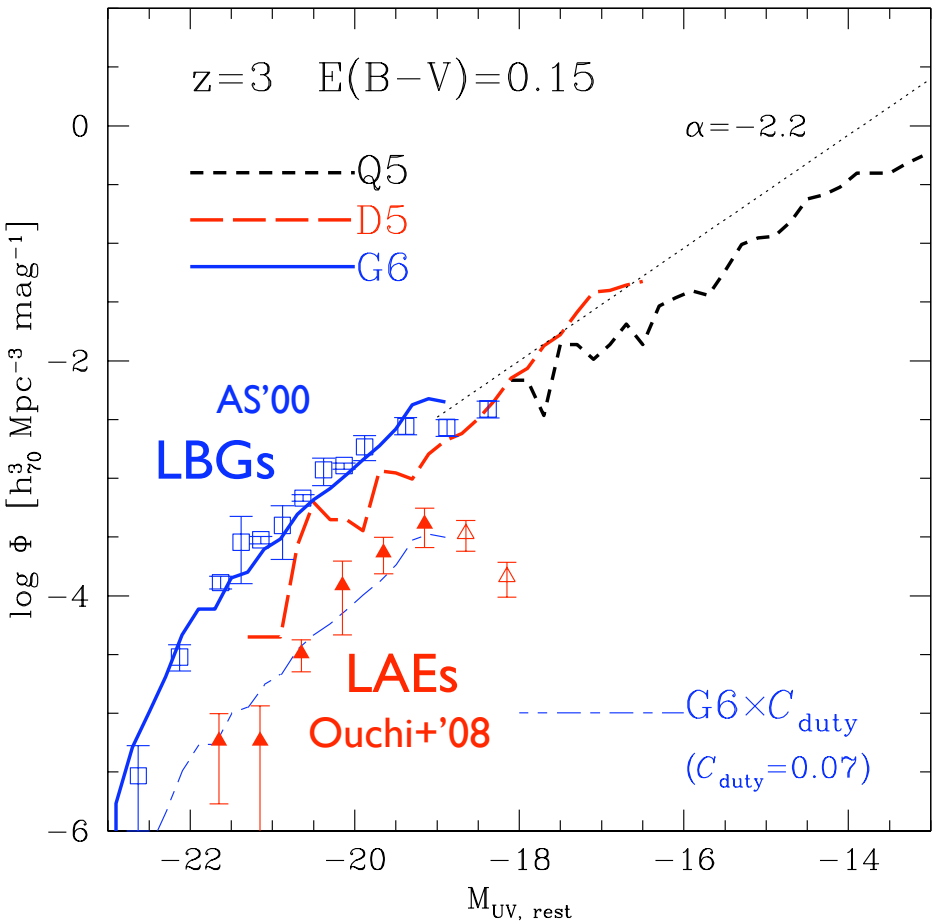


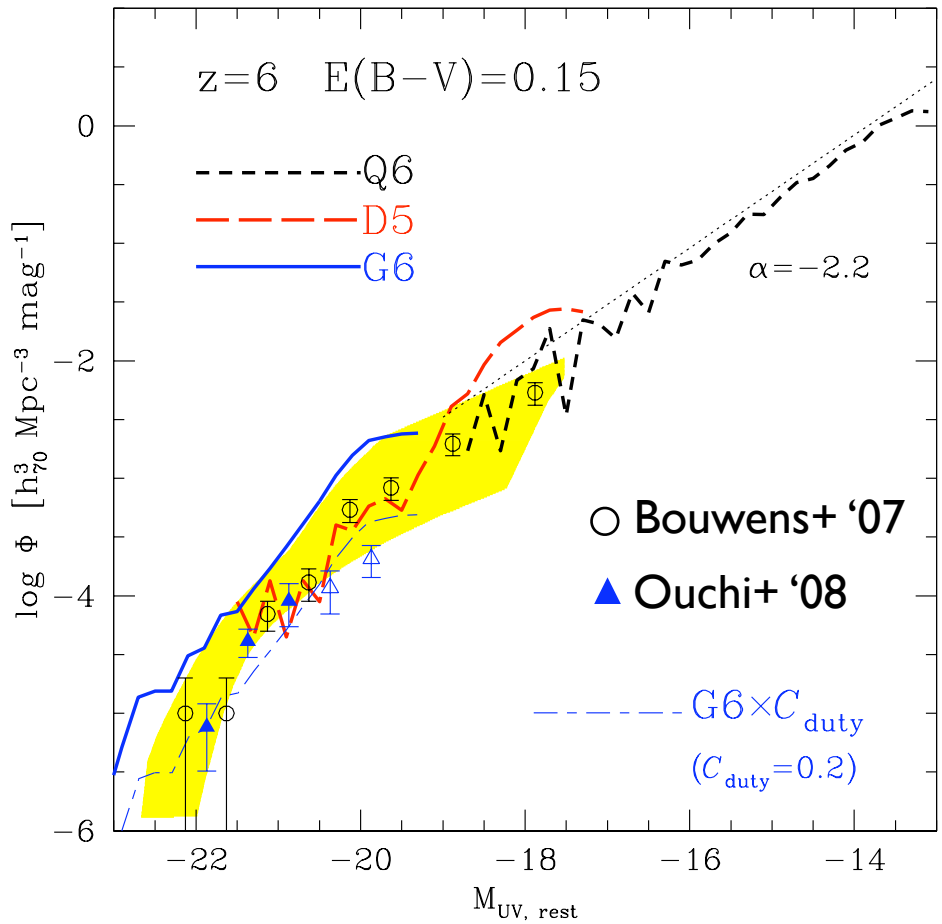
Duty cycle scenario



Not enough data @z=6.

UV LF of LAEs & LBGs



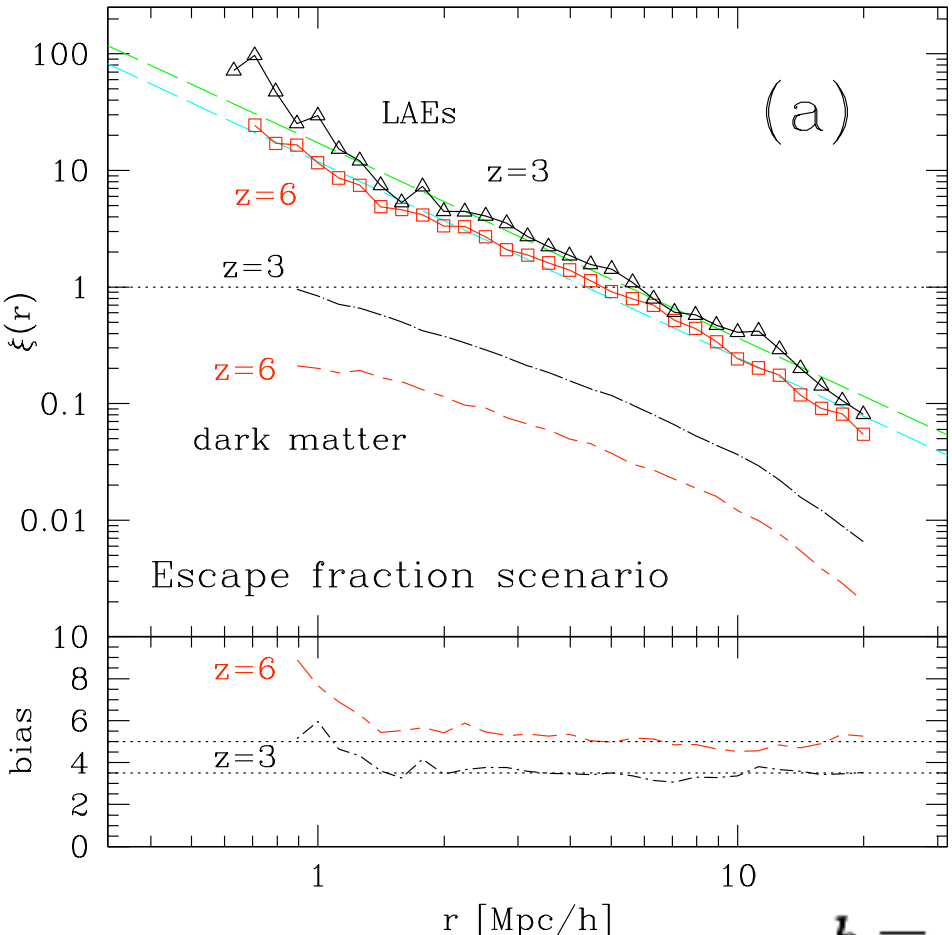


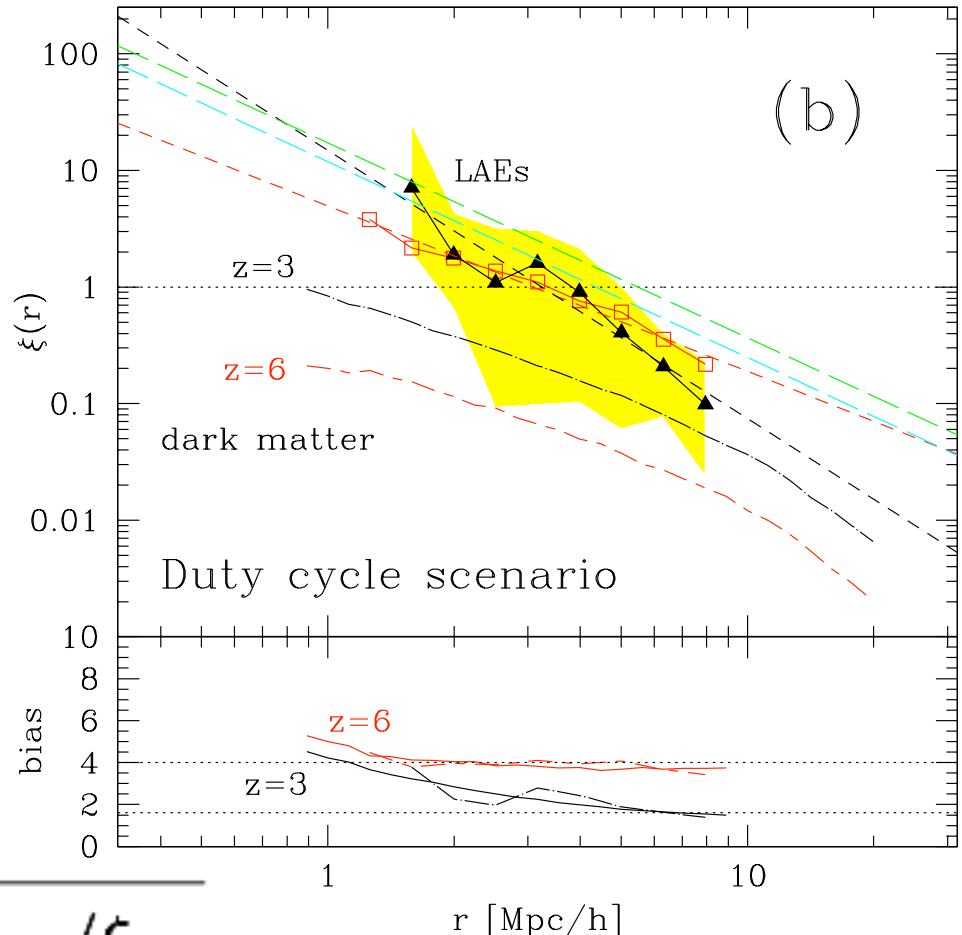
UV LFs of LAEs & LBGs can be described well, provided E(B-V)~0.15 for both population. (But recent obs suggest Ebv<~0.05)

Again, duty cycle scenario is favored.

We might be overpredicting the bright-end of the UV LF @z=6.

Correlation & Bias





$$b \equiv \sqrt{\xi_{\rm gal}/\xi_{\rm dm}}$$

Parameter	Escape Fraction Scenario $z=3$	Escape Fraction Scenario $z=6$	Duty Cycle Scenario $z=3$	Duty Cycle Scenario $z=6$
r_0 [n]	5.5	4.4	(3.2)	3.1
γ [p]	1.67	1.68	(2.30)	1.49
b [q]	3.5 (<6.0)	5.0 (<8.9)	(1.6–4.6)	4.0

Smaller r_0 and b for duty cycle scenario.

Gawiser+ '07 (z=3.1)

$r_0 = 3.6^{+0.8}_{-1.0}\,{\rm Mpc}$ $\quad b = 1.7^{+0.3}_{-0.4}$

Ouchi+ '05b (z=5.7)

$b = 3.4 \pm 1.8$ @ r ~8Mpc/h

KN+ '08: $b = 3.7$

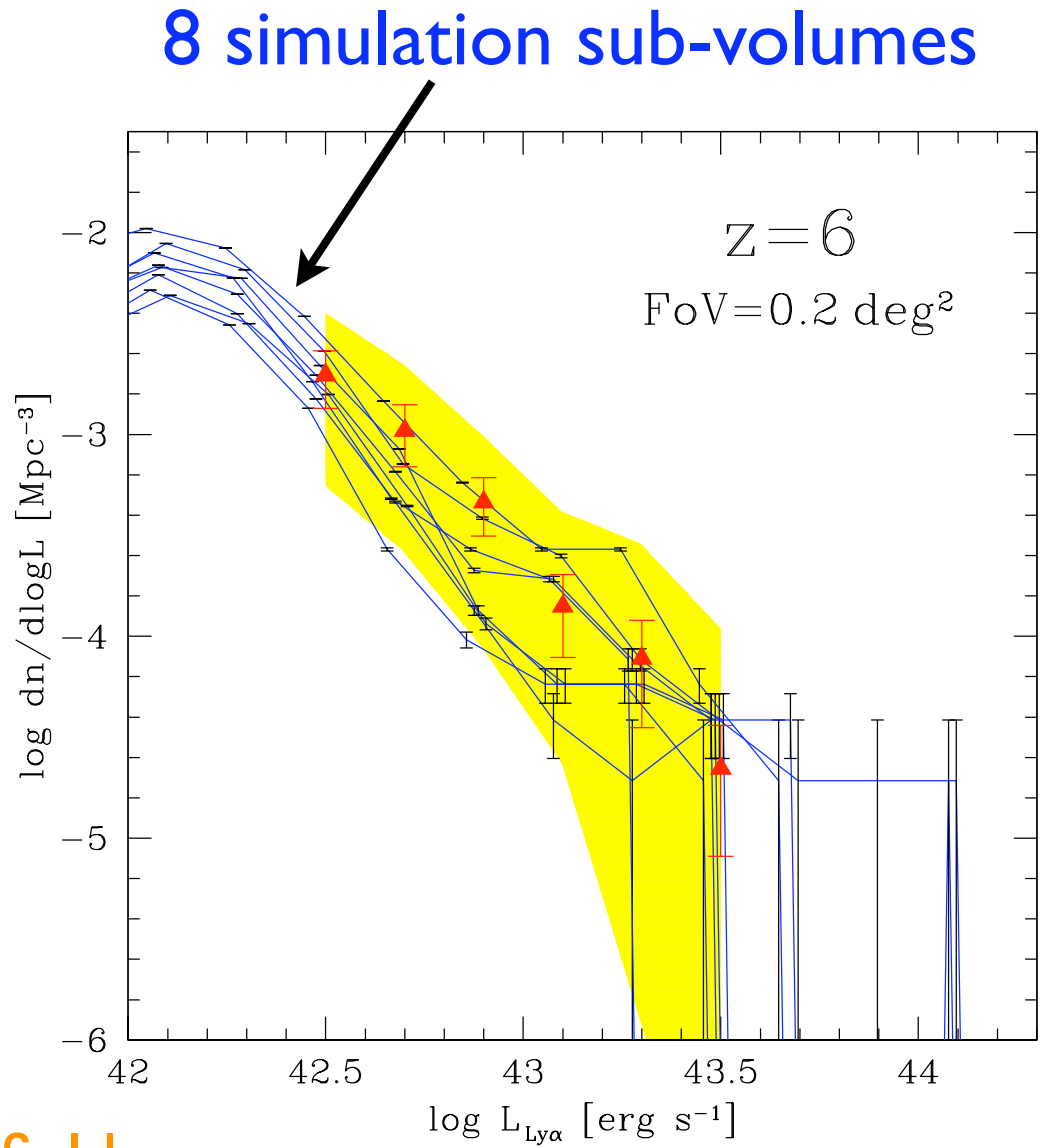
Summary of Parameters

Parameter	Escape Fraction Scenario $z = 3$	Escape Fraction Scenario $z = 6$	Duty Cycle Scenario $z = 3$	Duty Cycle Scenario $z = 6$
$f_{\mathrm{Ly}\alpha}$ [a]	0.10	0.15	—	—
f_{IGM} [b]	0.82 (1.0)	0.52 (1.0)	0.82 (1.0)	0.52 (1.0)
$f_{\mathrm{esc}}^{\mathrm{ion}}$ [c]	0.06	0.20	—	—
f_{dust} [d]	0.13 (0.11)	0.36 (0.19)	—	—
C_{duty} [e]	—	—	0.07 (0.06)	0.2 (0.06)
$\log(M_\star/M_\odot)$ [f]	$[10.2, 12.1]$	$[9.3, 11.0]$	$[9.2, 11.3]$	$[8.6, 10.3]$
$\langle M_\star/M_\odot \rangle$ [g]	2.5×10^{10}	1.9×10^{9}	3.8×10^{9}	6.1×10^{8}
$\rho_\star$ fraction [h]	0.18	0.11	0.42	0.29
$\log(M_{\mathrm{BH}}/M_\odot)$ [i]	$[7.7, 9.7]$	$[6.9, 8.7]$	$[6.7, 8.8]$	$[6.3, 8.0]$
$\langle M_{\mathrm{BH}}/M_\odot \rangle$ [j]	1.0×10^{8}	9.5×10^{6}	1.5×10^{7}	3.1×10^{6}
$\log(Z/Z_\odot)$ [k]	$[-0.7, 0.1]$	$[-1.3, -0.3]$	$[-1.0, 0.1]$	$[-1.4, -0.5]$
$\langle Z/Z_\odot \rangle$ [m]	0.39	0.17	0.21	0.11
r_0 [n]	5.5	4.4	(3.2)	3.1
γ [p]	1.67	1.68	(2.30)	1.49
b [q]	3.5 (< 6.0)	5.0 (< 8.9)	(1.6–4.6)	4.0

Duty cycle scenario: lower M*, lower $Z/Z_\odot$, less clustered, smaller bias

Cosmic Variance

- LFs in FoV=0.2 deg^2 show significant scatter
- Need FoV>1deg^2 for a reliable LF.



yellow shade:
Ouchi+ '08 FoV=0.2 deg^2 subfields

Conclusions

- Duty cycle scenario is favored over the Escape fraction scenario from the comparisons of M*-SFR relation, UV LF of LAEs, clustering & bias.
- If duty cycle scenario is correct, then LAEs would be a population w/ lower M*, lower metallicity, less clustered and less biased.
- Cosmic variance is strong, and can account for the scatter seen in current LF data from FoV<1 deg^2. (applies to both LBGs and LAEs)

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