A Semi-Analytic Model for high-z LAEs

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MARK et al. (2007, ApJ, 670, 919)
MARK et al. (2009, submitted to ApJ, arXiv:0902.2882)

THE THREE KEY POINTS OF THIS TALK

① **The effects of dust ext. & galactic-wind are incorporated in $f_{esc}^{Ly\alpha}$ in our model**

– $\tau_{dust}^{Ly\alpha}$ can be different from τ_{dust}^{c}

② **Our model predicts the dust dist. in ISM of high-z LAE is clumpy**

– our model results: $\tau_{dust}^{Ly\alpha} = 0.15\tau_{dust}^{c}$

③ **Applying the same EW threshold is important when the redshift evolutions of LAE UVLF and LAE/LBG fraction are examined**

– the bright-end of LAE UVLF depends on EW^{th}

□ **Comments to the claims to our model predictions from K. Nagamine and D. Schaerer**

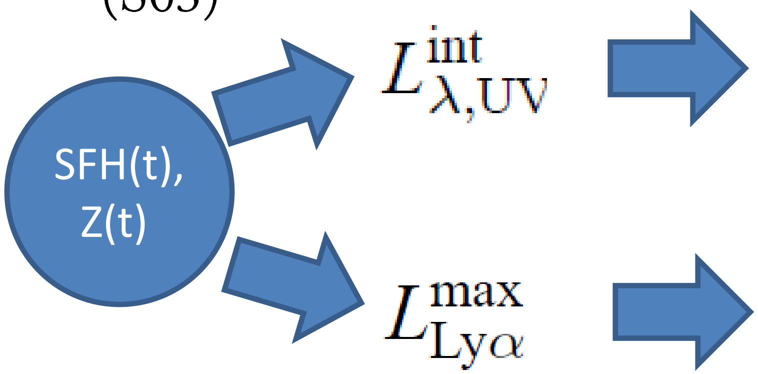
MODEL DESCRIPTION (1)

- Base: a semi-analytic model (the Mitaka model, Nagashima & Yoshii04)
  - SFH, Z, Mstar, Mgas, size, … of each model galaxy can be obtained
  - 2 SF types = quiescent and starburst
  - 3 distinctive phases of starbursts = pre-outflow, outflow, and post-outflow

- L_{Lya} & $L_{\lambda,UV}$ (λ=1500 Å)

population synthesis model of Schaerer03 (S03)

$$f_{\rm esc}^{\rm UV} = \frac{1-e^{-\tau_{\rm dust}^{c}}}{\tau_{\rm dust}^{c}}, \quad \tau_{\rm dust}^{c} \propto N_{\rm cold} Z_{\rm cold}$$



$$L_{\lambda,{\rm UV}}^{\rm int} \Rightarrow L_{\lambda,{\rm UV}}^{\rm obs} = L_{\lambda,{\rm UV}}^{\rm int} f_{\rm esc}^{\rm UV}$$

$$L_{{\rm Ly}\alpha}^{\rm max} \Rightarrow L_{{\rm Ly}\alpha}^{\rm obs} = L_{{\rm Ly}\alpha}^{\rm max} \left(1 - f_{\rm esc}^{\rm LyC}\right) f_{\rm esc}^{{\rm Ly}\alpha} T_{\rm IGM}^{{\rm Ly}\alpha}$$

S03 model, case B, all LyC photons are absorbed by HI

$$f_{\rm esc}^{\rm LyC} = 0, \quad T_{\rm IGM}^{{\rm Ly}\alpha} = 1$$

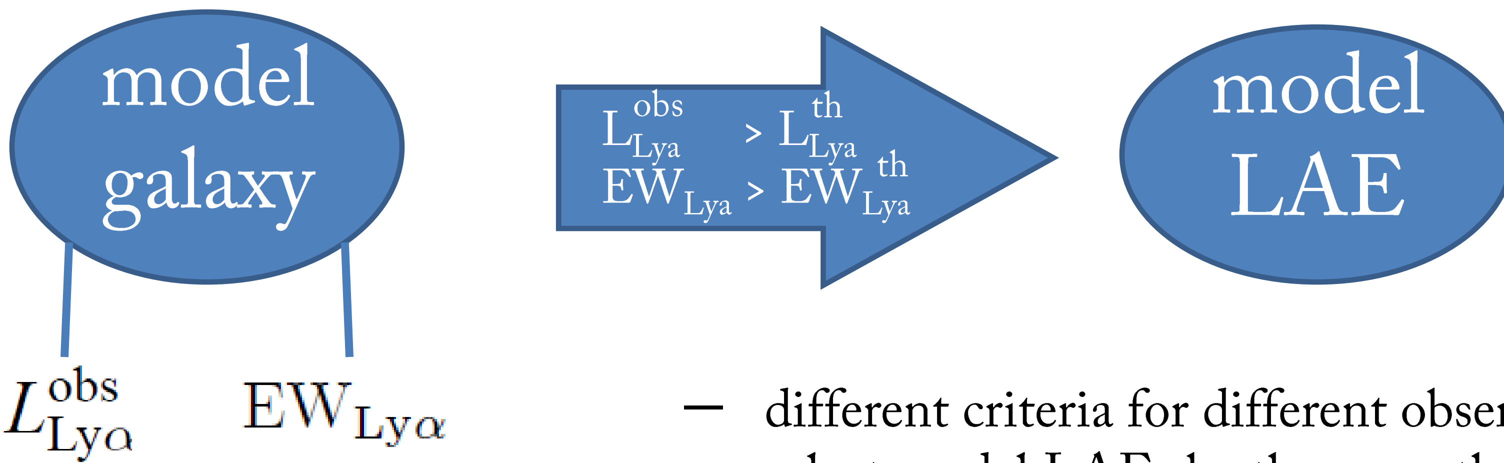
MODEL DESCRIPTION (2)

□ Lyα EW

$$L_{\lambda,\mathrm{UV}}^{\mathrm{int}} + L_{\mathrm{Ly}\alpha}^{\mathrm{max}} \rightarrow \quad \mathrm{EW}_{\mathrm{Ly}\alpha}^{\mathrm{int}} = \frac{L_{\mathrm{Ly}\alpha}^{\mathrm{max}}}{L_{\lambda,\mathrm{UV}}^{\mathrm{int}} \left(1500\ \text{Å}/1216\ \text{Å}\right)^2}$$

$$L_{\lambda,\mathrm{UV}}^{\mathrm{obs}} + L_{\mathrm{Ly}\alpha}^{\mathrm{obs}} \rightarrow \quad \mathrm{EW}_{\mathrm{Ly}\alpha} = \frac{L_{\mathrm{Ly}\alpha}^{\mathrm{obs}}}{L_{\lambda,\mathrm{UV}}^{\mathrm{obs}} \left(1500\ \text{Å}/1216\ \text{Å}\right)^2}$$

□ Model LAE Selection



- different criteria for different observations
- select model LAEs by the same thresholds as those adopted in each observation

① PHENOMENOLOGICAL MODEL FOR $f_{esc}^{Ly\alpha}$

□ **outflow+dust model**

– for quiescent and pre-outflow starburst : $f_{esc}^{Ly\alpha} = f_0 \frac{1-\exp(-\tau_d^{Ly\alpha})}{\tau_d^{Ly\alpha}}$ $\tau_d^{Ly\alpha} = \frac{N_{cold} Z_{cold}}{(N_{cold} Z_{cold})_0^{Ly\alpha}}$

– for outflow starburst : $f_{esc}^{Ly\alpha} = f_0^{wind}$

… the onset time of galactic wind, t_{wind}, is determined by the Mitaka model

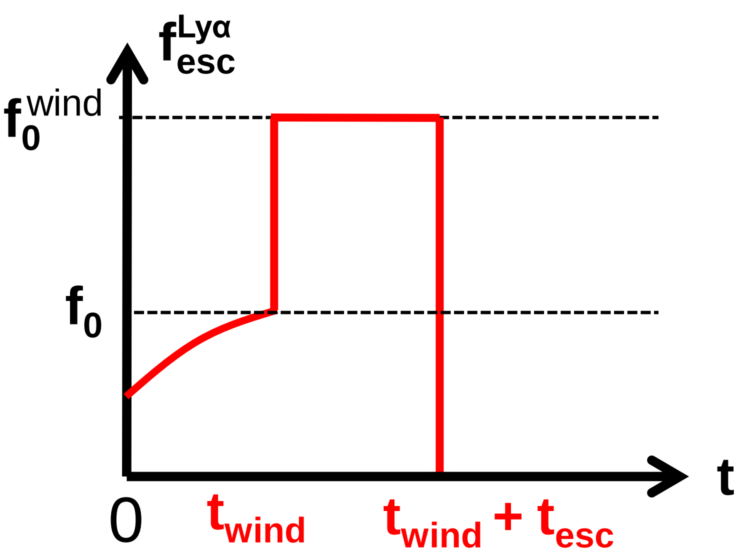
– for post-outflow starburst : $L_{Ly\alpha}^{max} = 0$

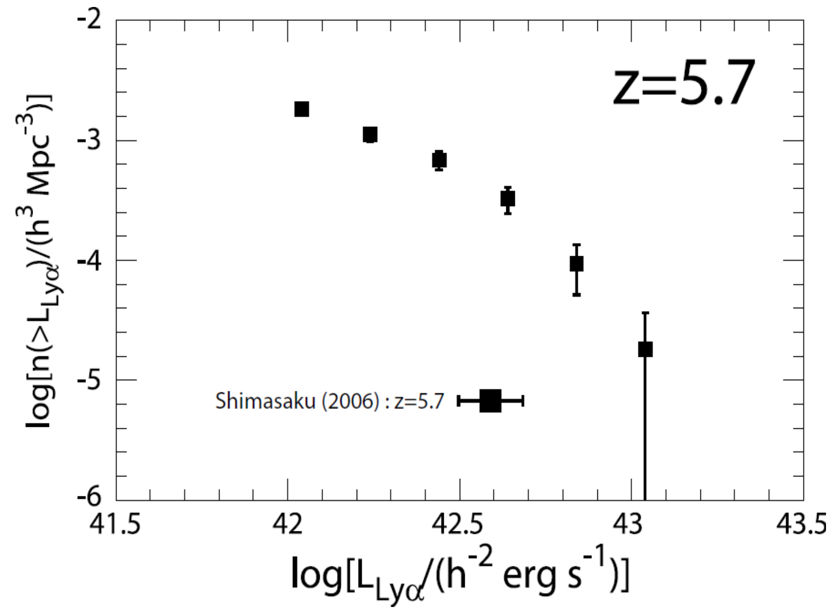
… the timescale for ISM escaping from the galaxy via wind, t_{esc}, is estimated by R_{gal} / V_{esc}

– the values of three model parameters

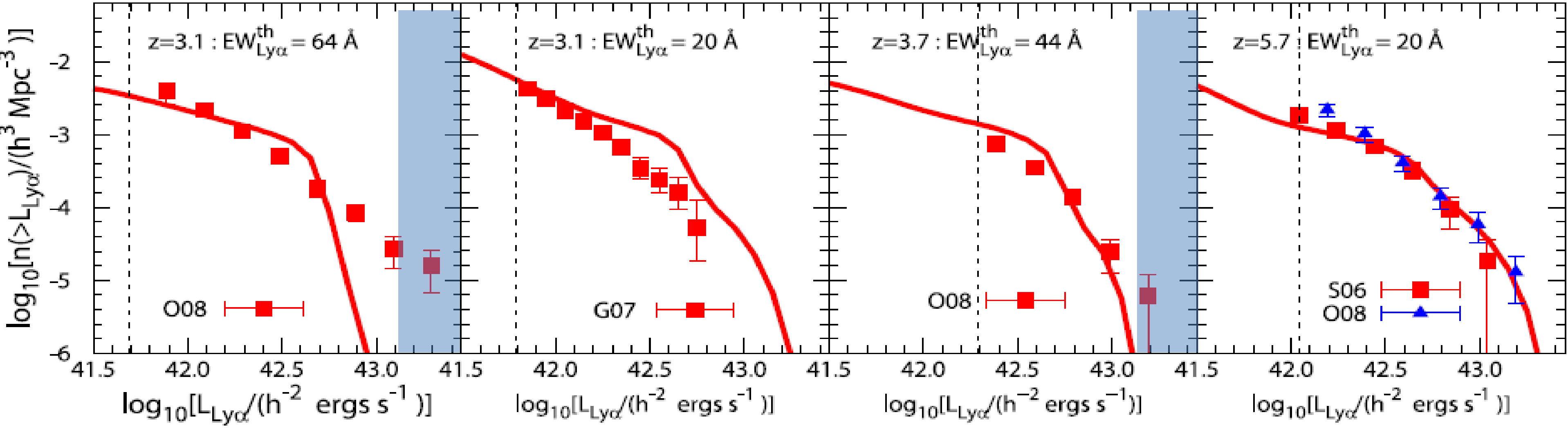
… determined to fit the Lyα LF of the LAEs @ z=5.7 in SDF (Shimasaku+06)

➔ no z-evolution is assumed





COMPARISONS WITH OBS. DATA



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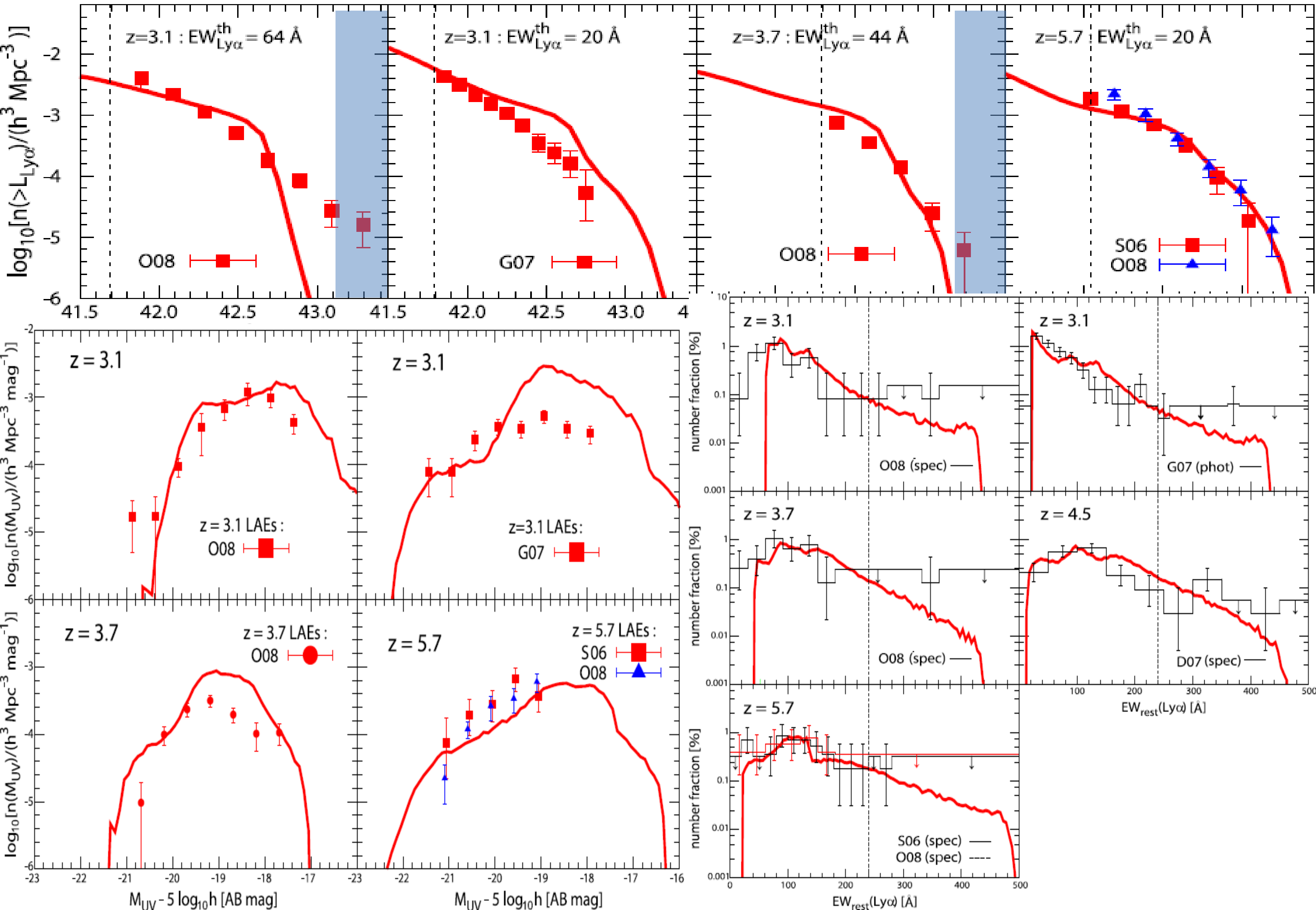

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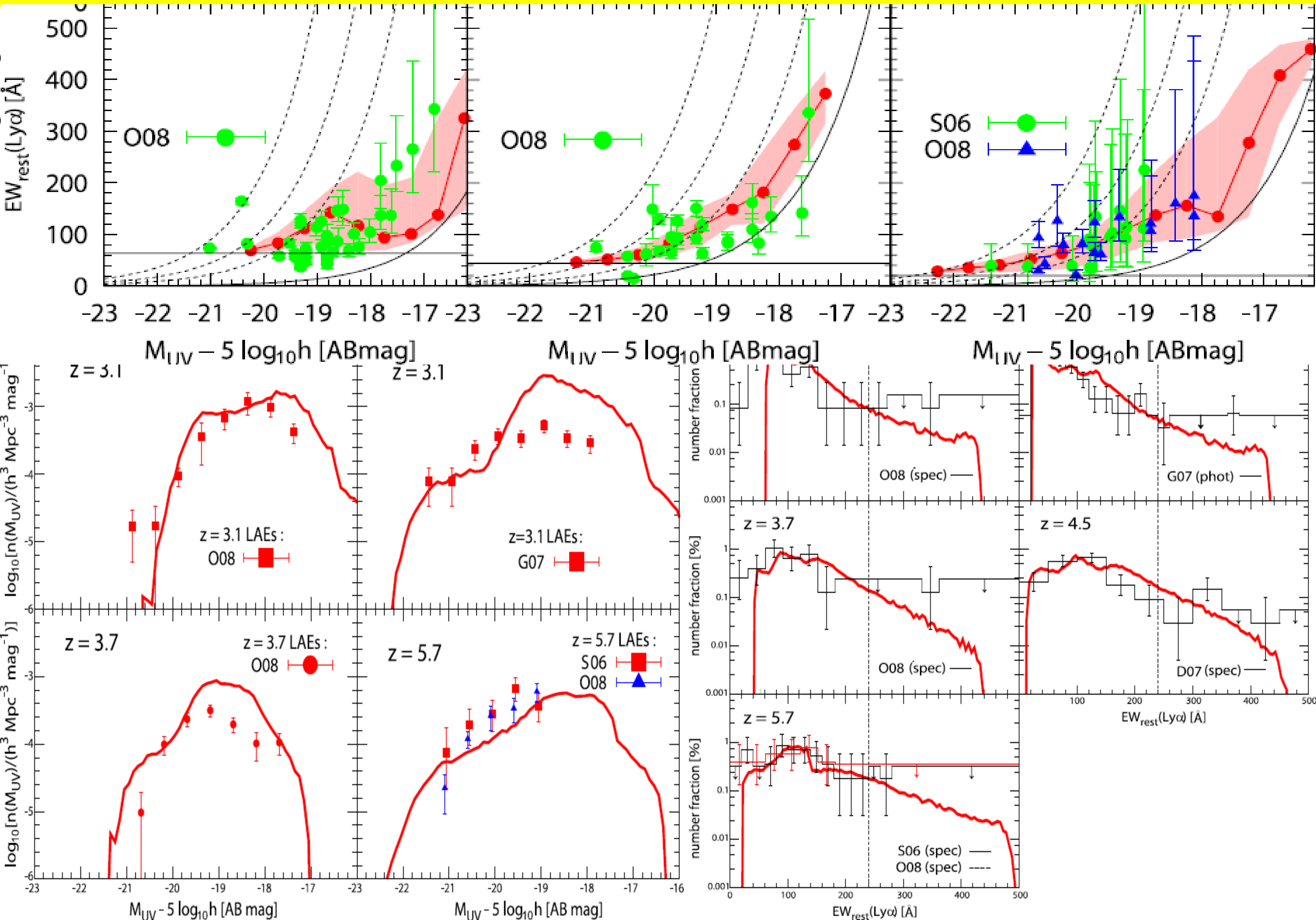


② IMPLICATION FOR THE ISM GEOMETRY

- Our model separately defines $\tau_{\rm dust}^{\rm Ly\alpha}$ and $\tau_{\rm dust}^{\rm c}$
  - Lyα line : $\tau_d^{\rm Ly\alpha} = \frac{N_{\rm cold} Z_{\rm cold}}{(N_{\rm cold} Z_{\rm cold})_0^{\rm Ly\alpha}}$
  - UV continuum : $\tau_{\rm dust}^{c} \propto N_{\rm cold} Z_{\rm cold}$

$$\tau_d^{\rm Ly\alpha} \equiv q_d \, \tau_d^{\rm c}(\lambda_{\rm Ly\alpha})$$

$$\Gamma \equiv \frac{\rm EW_{Ly\alpha}}{\rm EW_{Ly\alpha}^{int}} = \frac{f_0}{q_d} \frac{1-\exp[-q_d \tau_d^{\rm c}(\lambda_{\rm Ly\alpha})]}{1-\exp[-\tau_d^{\rm c}(\lambda_{\rm Ly\alpha})]}$$

➔ q_d : geometry (or clumpiness) parameter (Finkelstein+09)

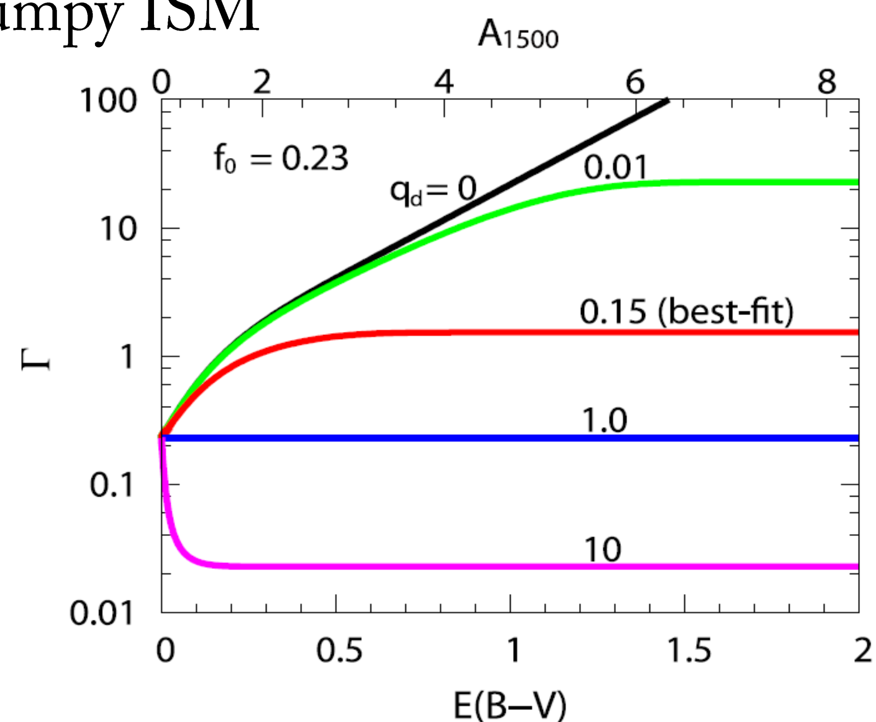
① q_d >> 1 … homogeneous ISM

② q_d << 1 … extremely clumpy ISM

- Our best-fit parameter
  - $q_d = 0.15 < 1$

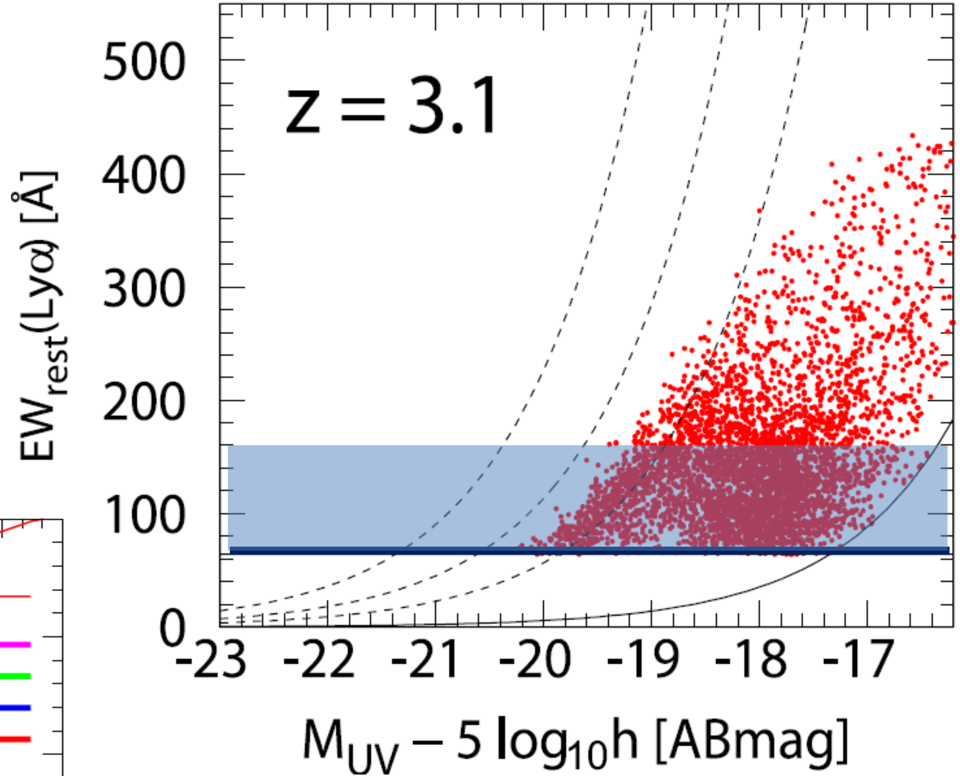
the ISM of high-z LAEs is clumpy

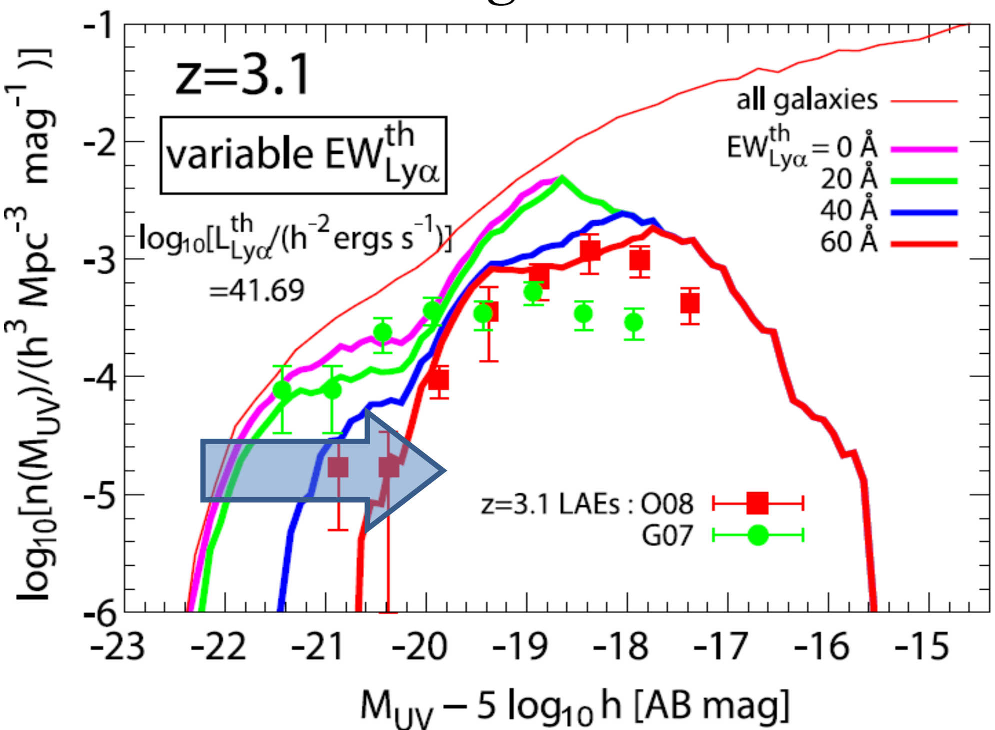
➔ $\Gamma < 1.5$



③ DEPENDENCE OF UVLF ON $EW^{th}_{Ly\alpha}$

- It is easily explained from the dist. of LAEs in the M_{UV}-EW plane
  - larger $EW^{th}_{Ly\alpha}$
    → fainter bright-end (smaller # density at the bright-end)

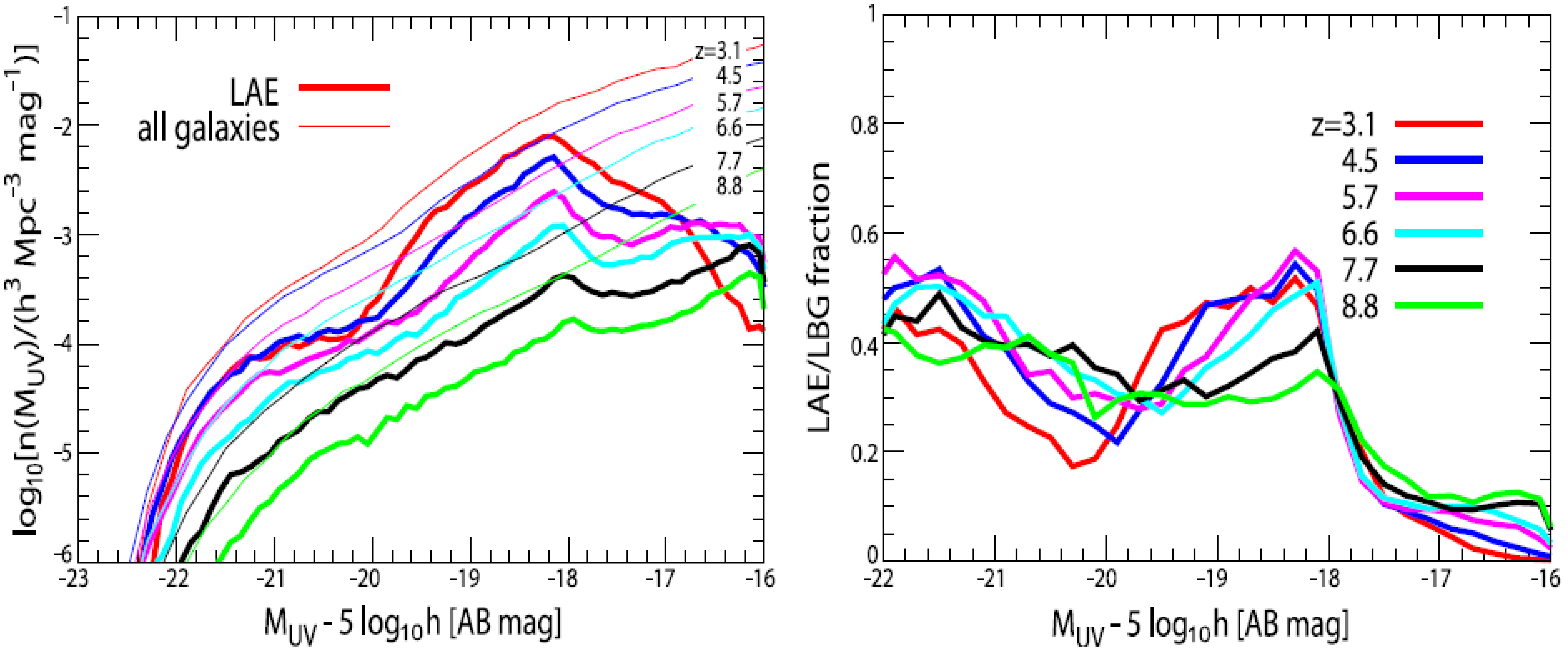




Selection conditions of LAEs are very important when the redshift evolutions of these quantities are discussed

PREDICTION TO z-EVOLUTION OF LAE

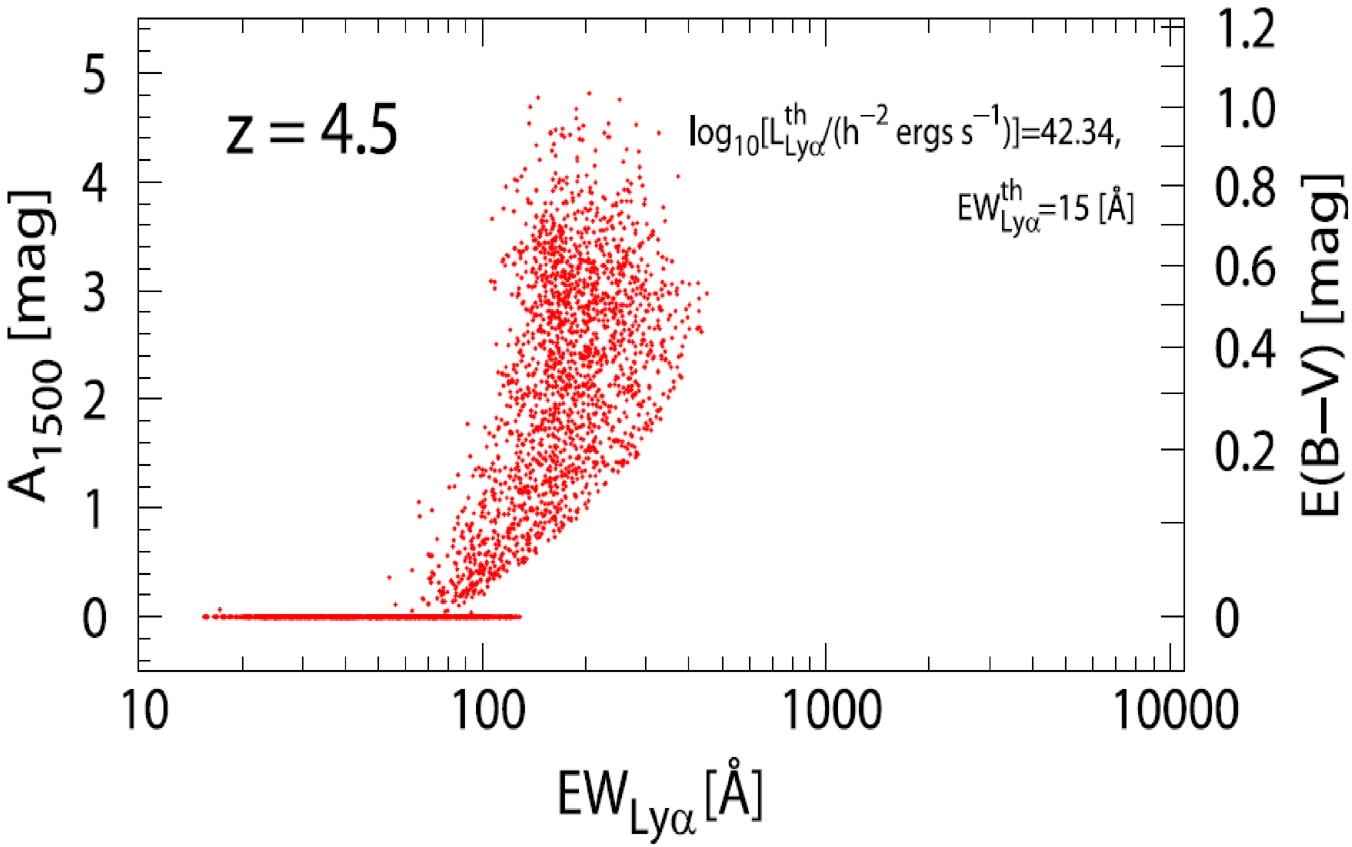
- **Selection criteria:** $L_{Ly\alpha}^{th} = 10^{41.5}$ erg/s/h^2 , $EW_{Ly\alpha}^{th} = 20$ A
  - LAE UVLF becomes fainter as z increasing (for z>3)
    it follows hierarchical evolution as LBG UVLF
  - LAE/LBG fraction is almost constant for z=3-9



COMMENT TO THE Nagamine's TALK

- A correlation among E(B-V) and $EW_{Ly\alpha}$
  - larger E(B-V) → larger $EW_{Ly\alpha}$

    but clearly shown at $EW_{Ly\alpha}$ > 100 A
  - there has been no obs. result which can test the prediction



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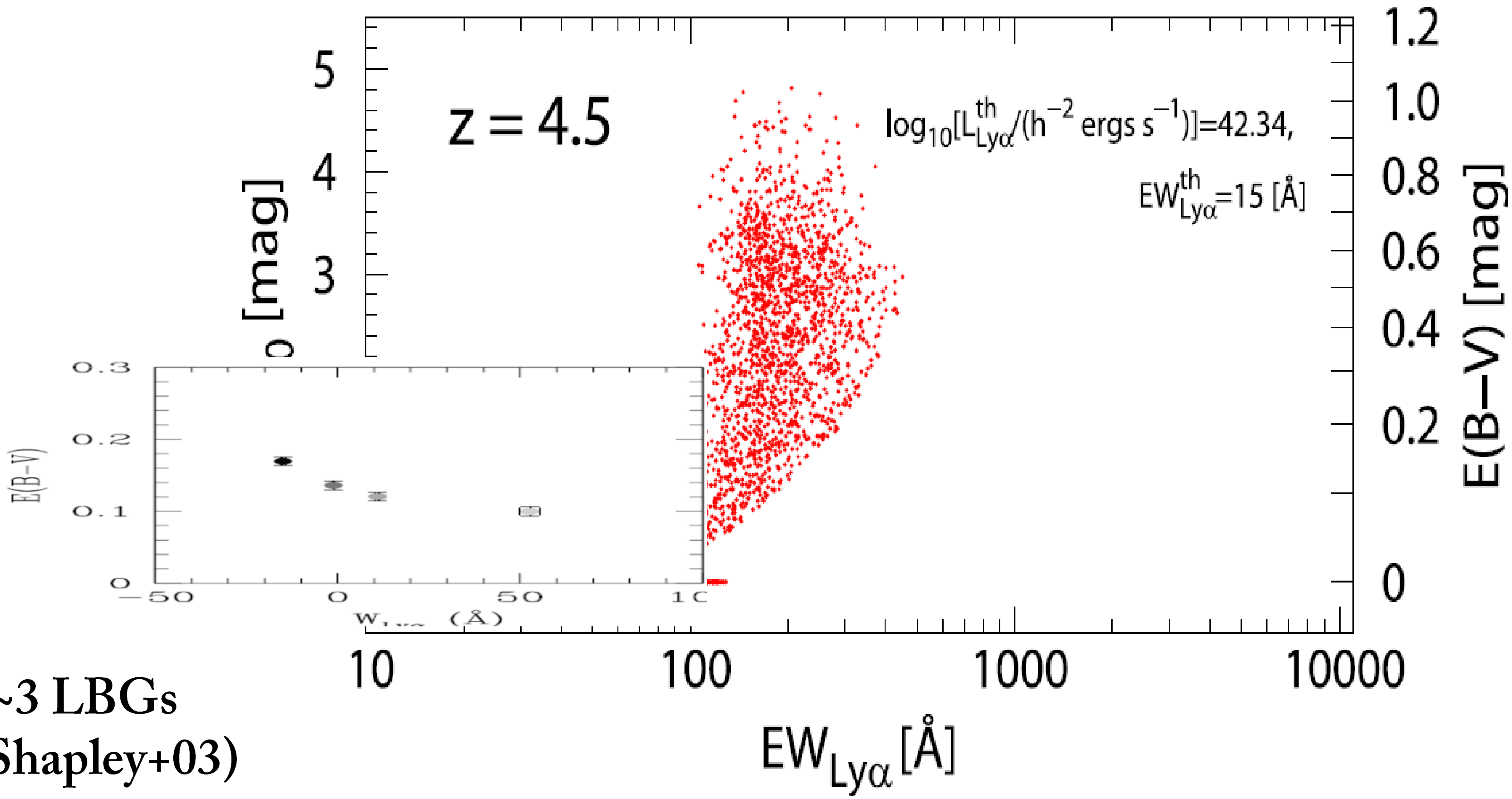

z~3 LBGs
(Shapley+03)

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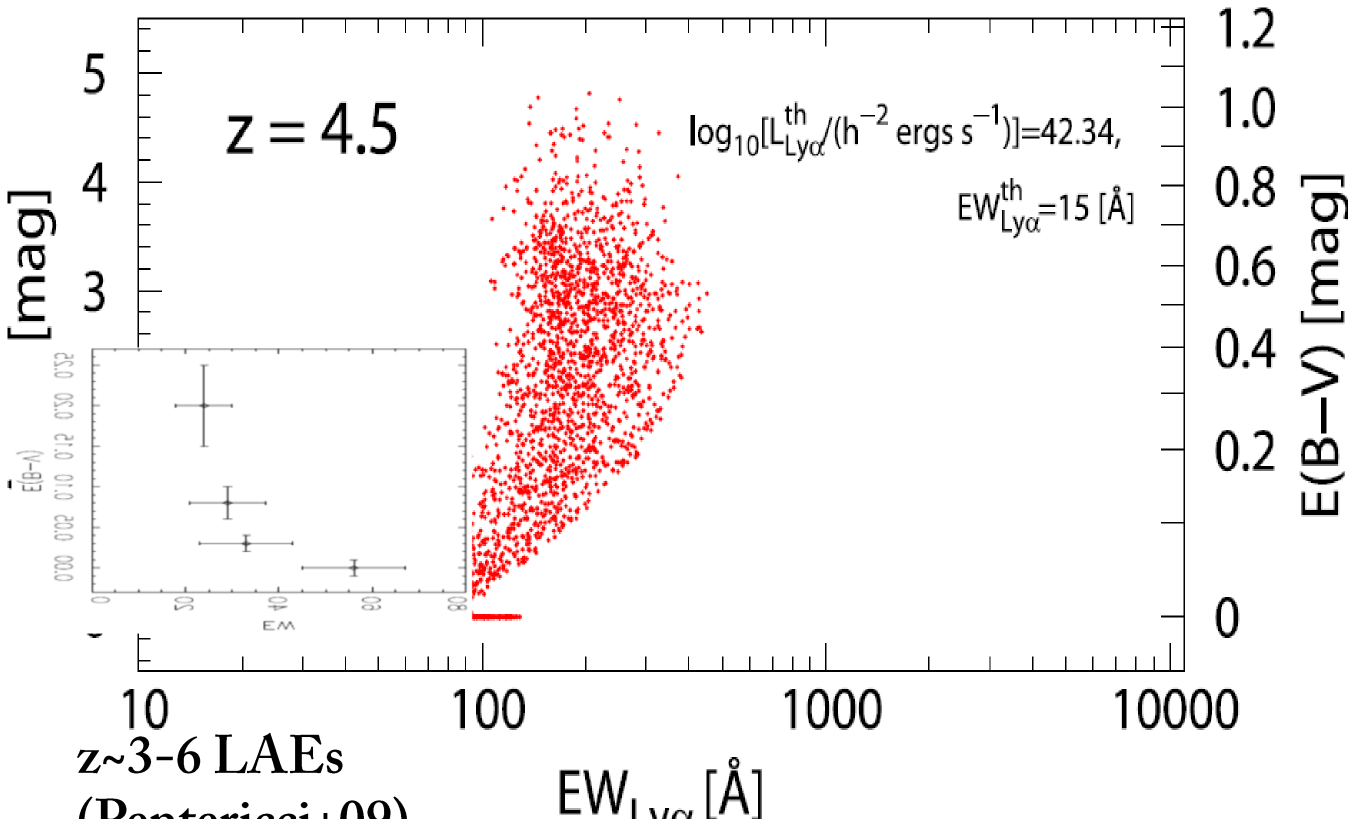
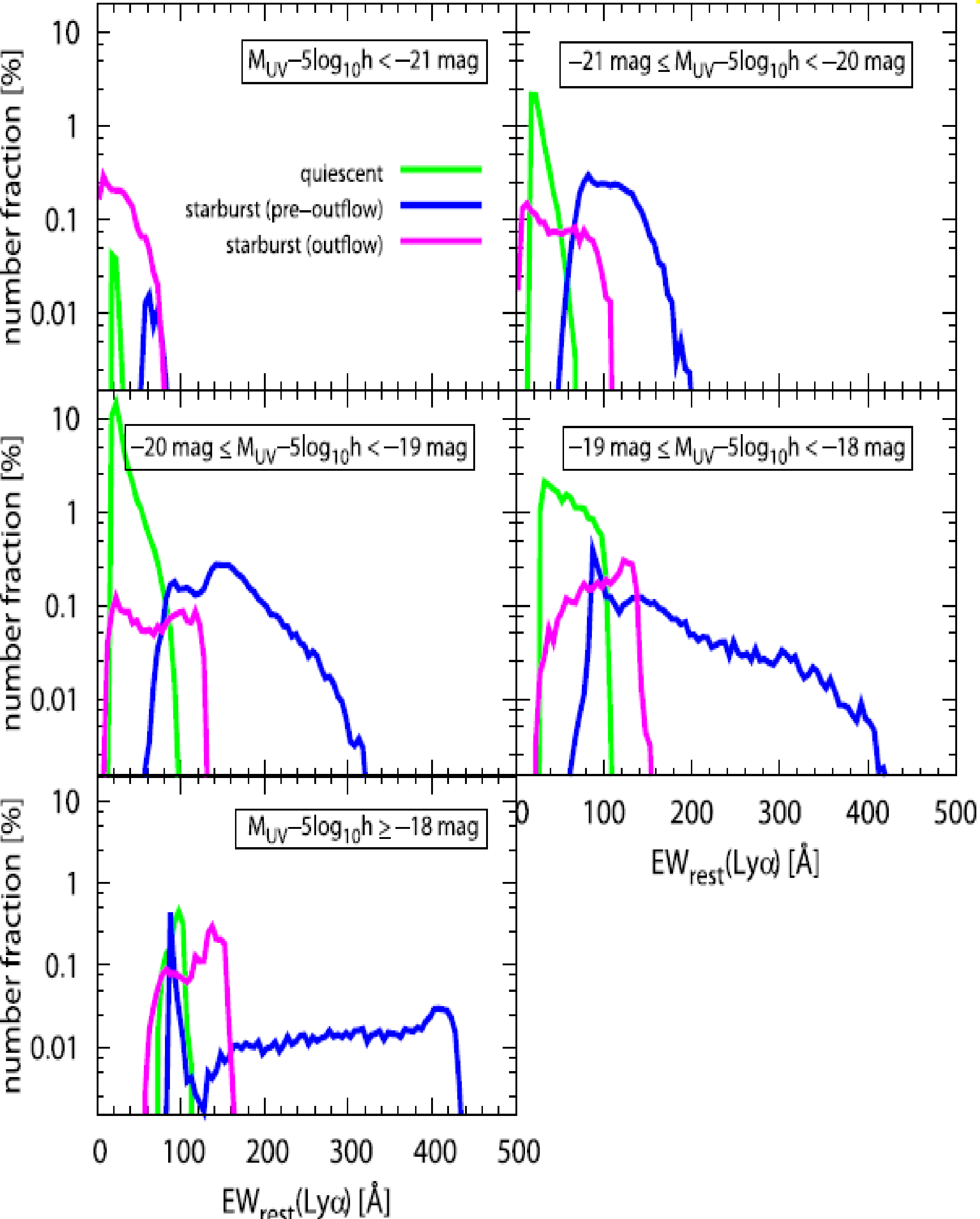


z~3-6 LAEs
(Pentericci+09)

COMMENT TO THE Schaerer's TALK



– the emergence of the galaxies w/ large E(B-V) at fainter M_{UV}

– larger E(B-V) leads to larger EW

➔ larger EW at fainter M_{UV}

– M_{UV} is the observable one (i.e., uncorrected for dust extinction)

– there is no observed signature that shows M_{UV} correlates with E(B-V)

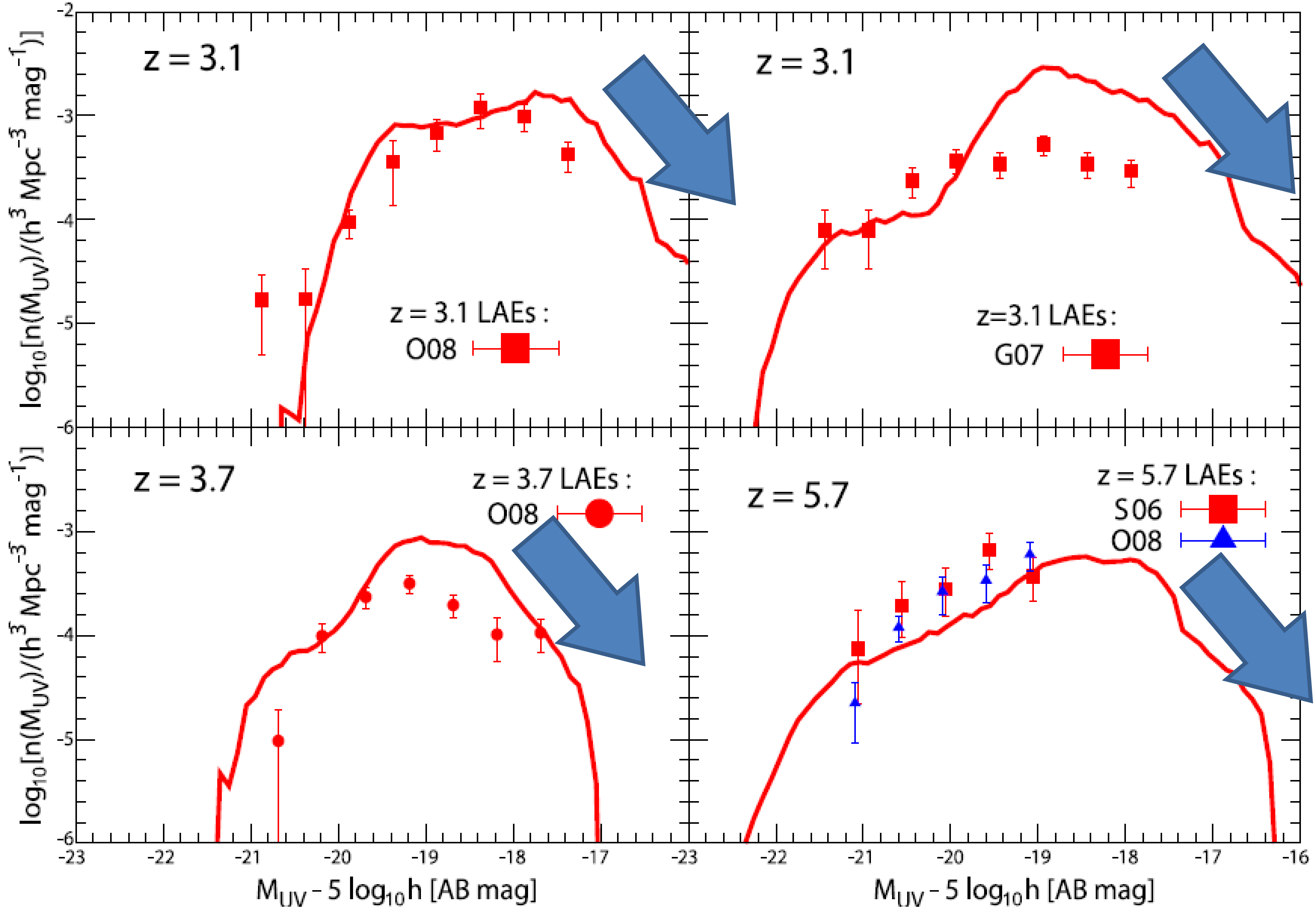
– intrinsic M_{UV} (i.e., corrected for dust ext.) correlates with E(B-V)

CONCLUSIONS

- Our LAE model reproduces the obs. data of the high-z LAEs well
- Our model predicts the dust dist. in ISM of high-z LAE is clumpy
- Applying the same EW criterion is important when the redshift evolution of LAE UVLF and LAE/LBG fraction is examined
- Our model would be helpful in planning an LAE survey and for interpretation of the obs. data at high-z ($z > 3$)

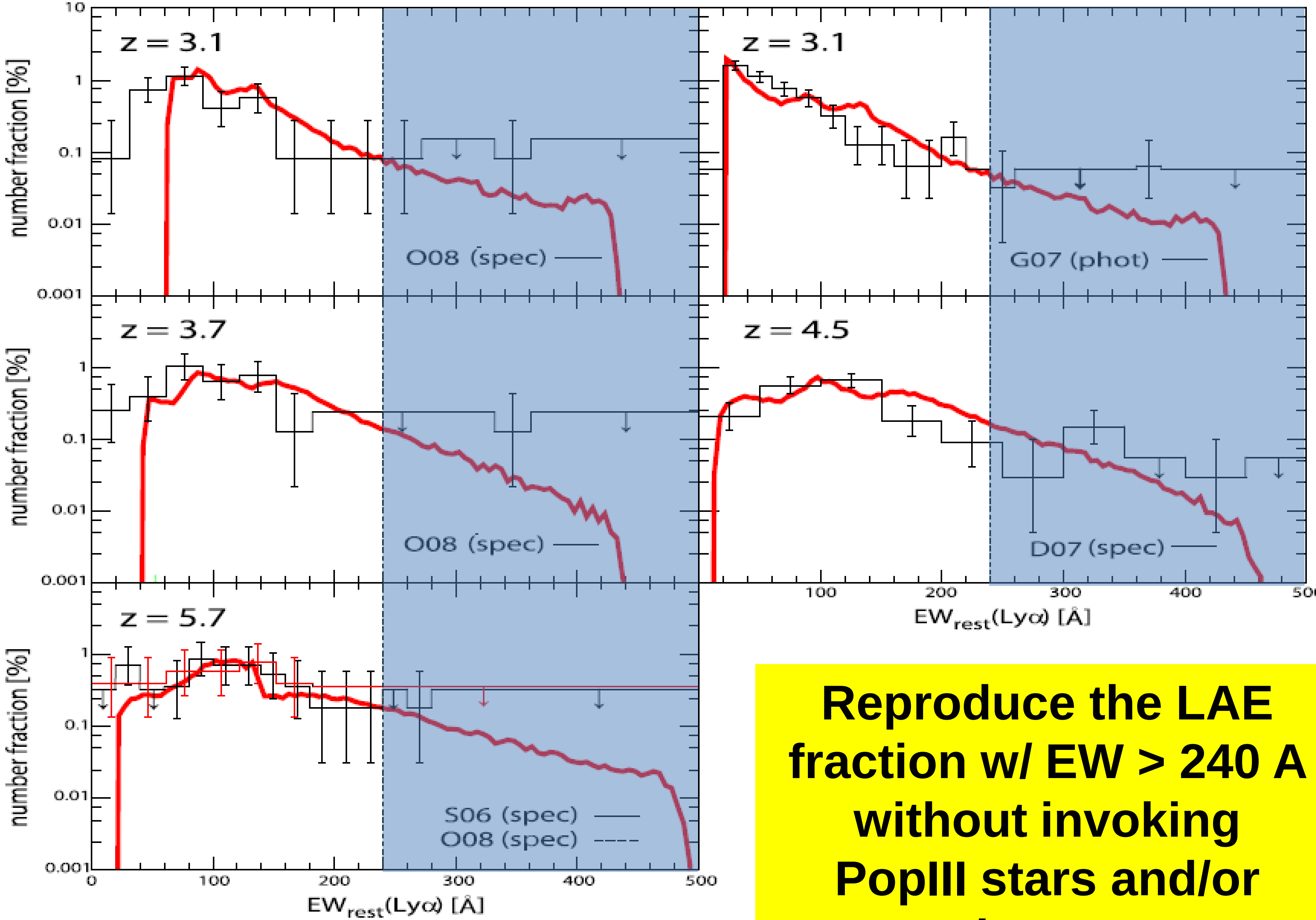
The numerical data on various quantities of LAEs @ z > 3 are available upon request to MARK!!

LAE UVLF @ z < 6



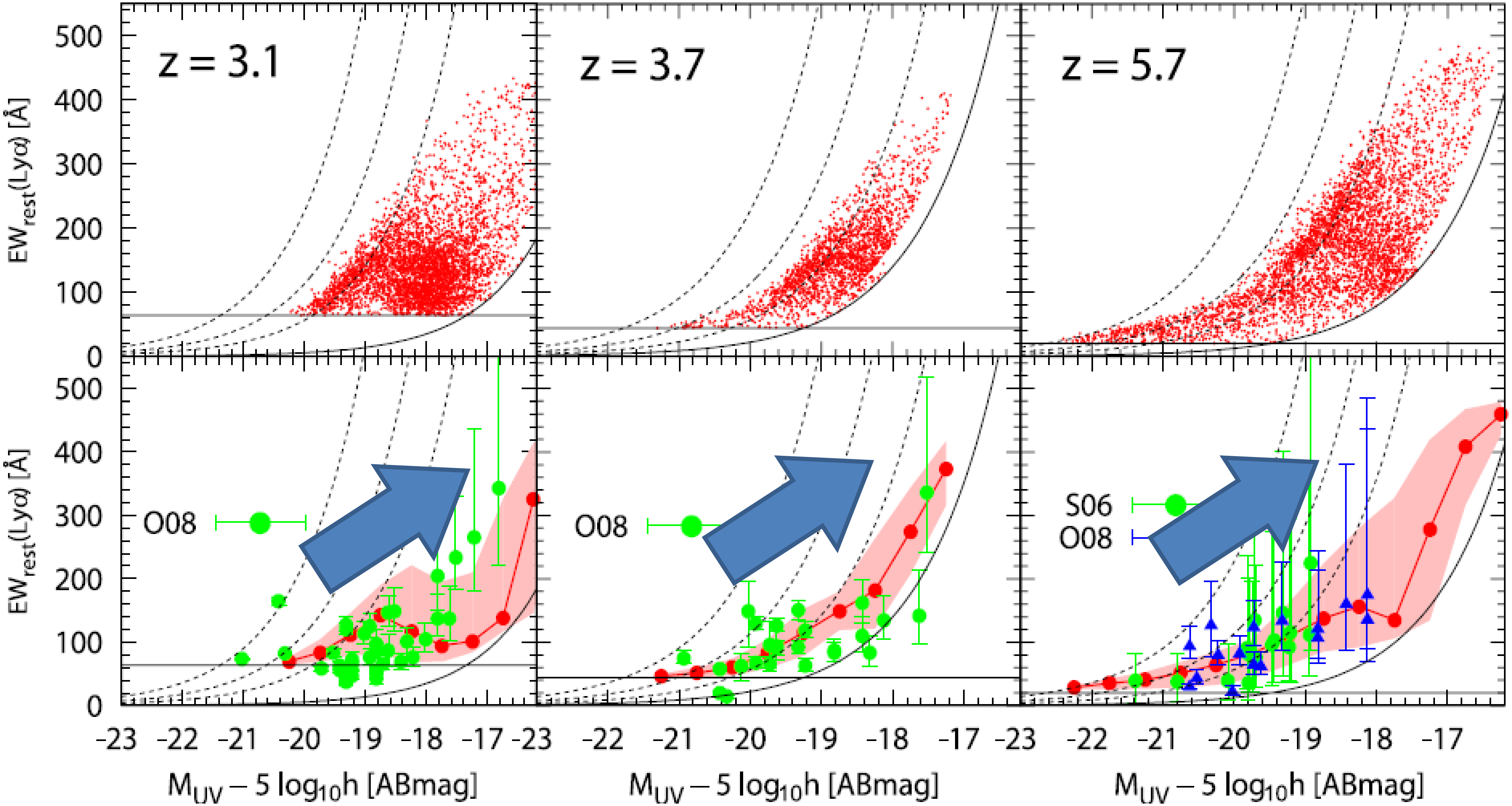
z = 3.1
z = 3.1 LAEs :
O08
z = 3.1
z=3.1 LAEs :
G07
z = 3.7
z = 3.7 LAEs :
O08
z = 5.7
z = 5.7 LAEs :
S06
O08
log10[n(MUV)/(h3 Mpc-3 mag-1)]
MUV - 5 log10h [AB mag]

EW DISTRIBUTION @ z < 6



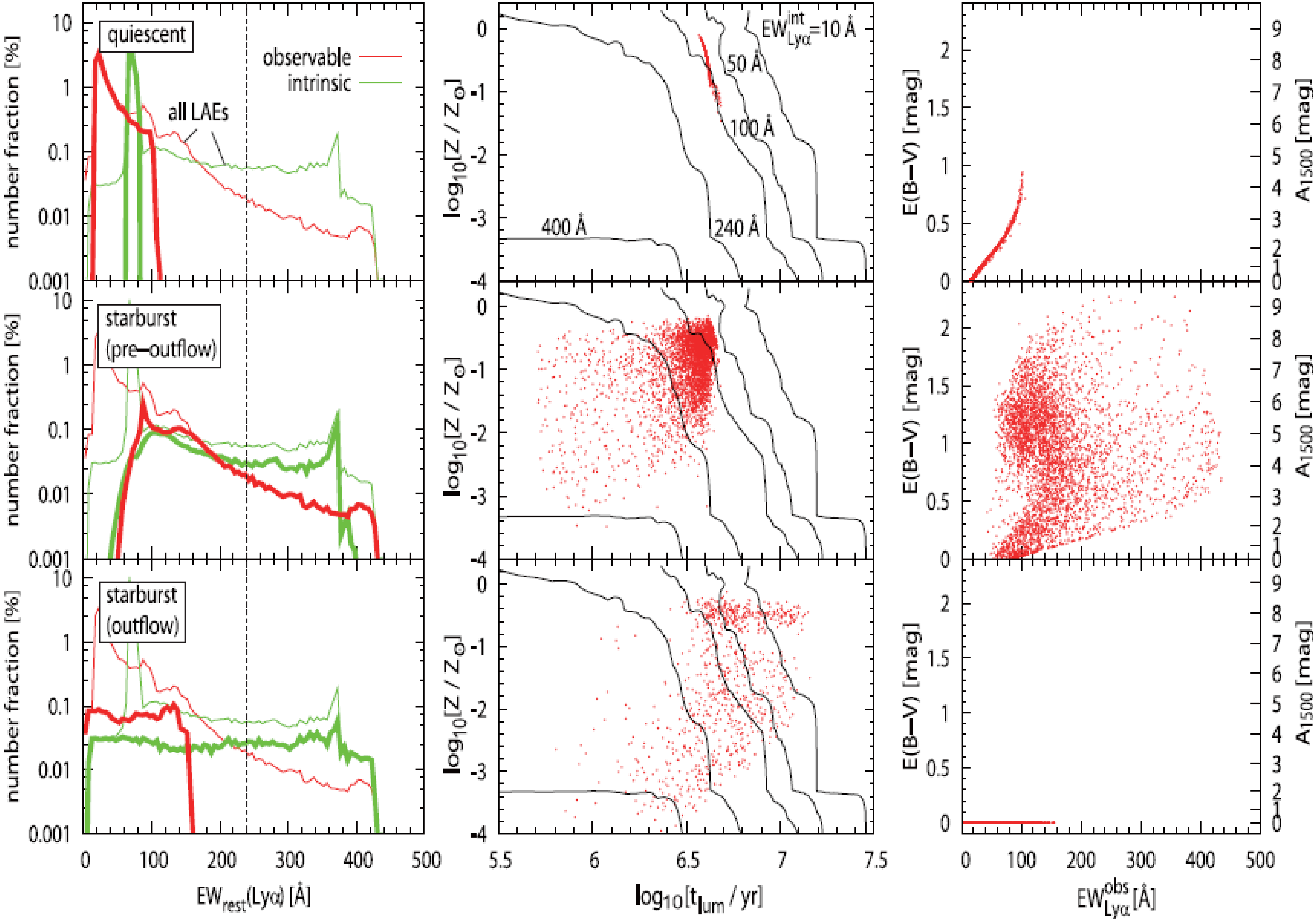
Reproduce the LAE fraction w/ EW > 240 A without invoking PopIII stars and/or top-heavy IMF

DISTRIBUTION IN THE M_{UV} - EW PLANE @ z<6

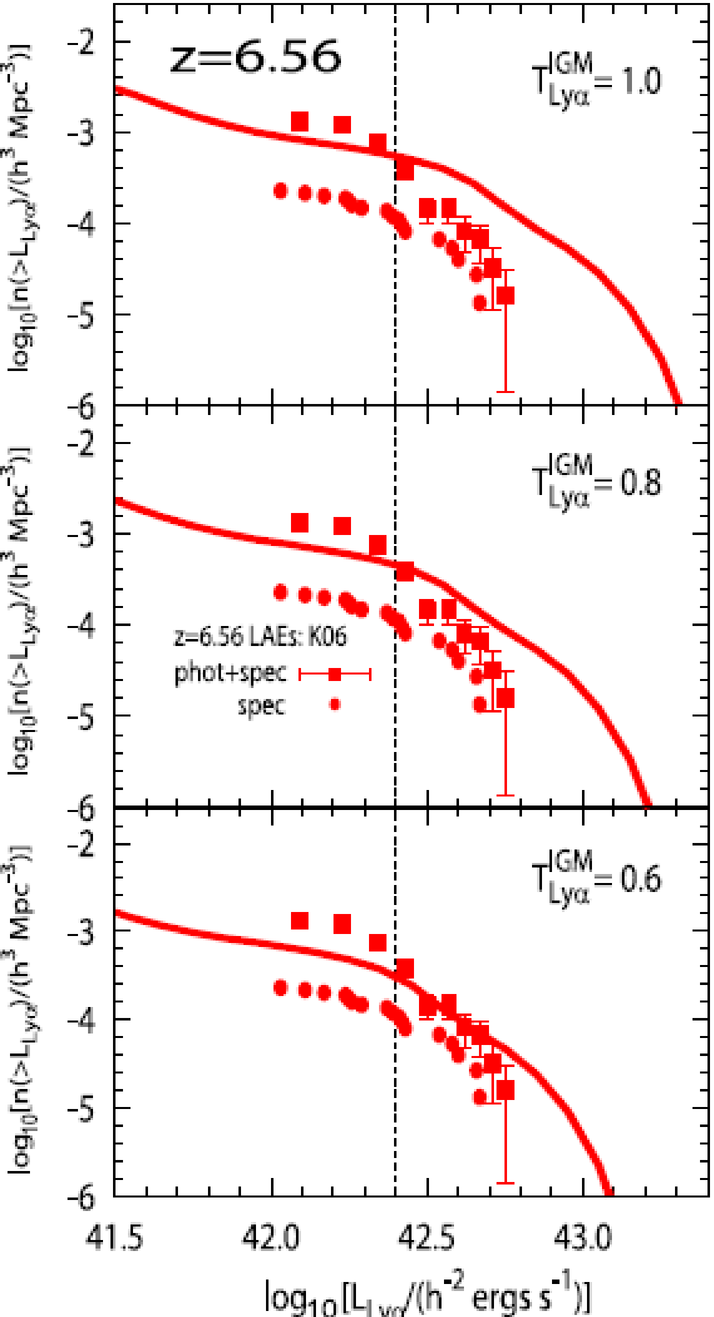


Our model is the first one which quantitatively reproduces the observed distribution in the plane

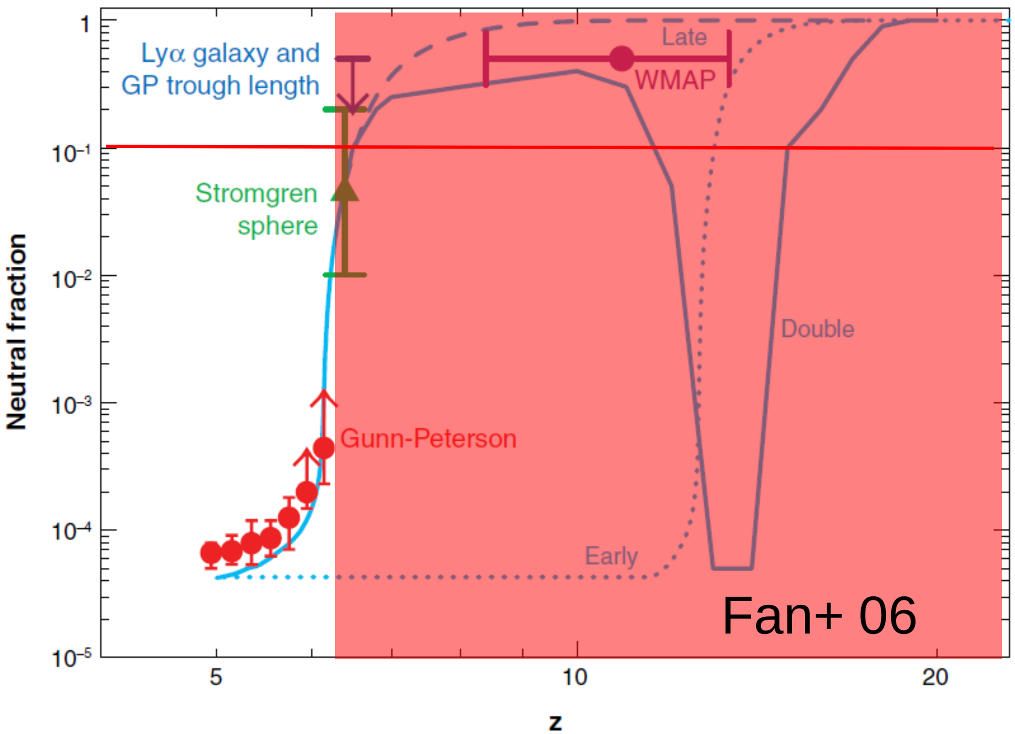
METALLICITY & AGE OF MODEL LAE



Lyα LF @ z > 6

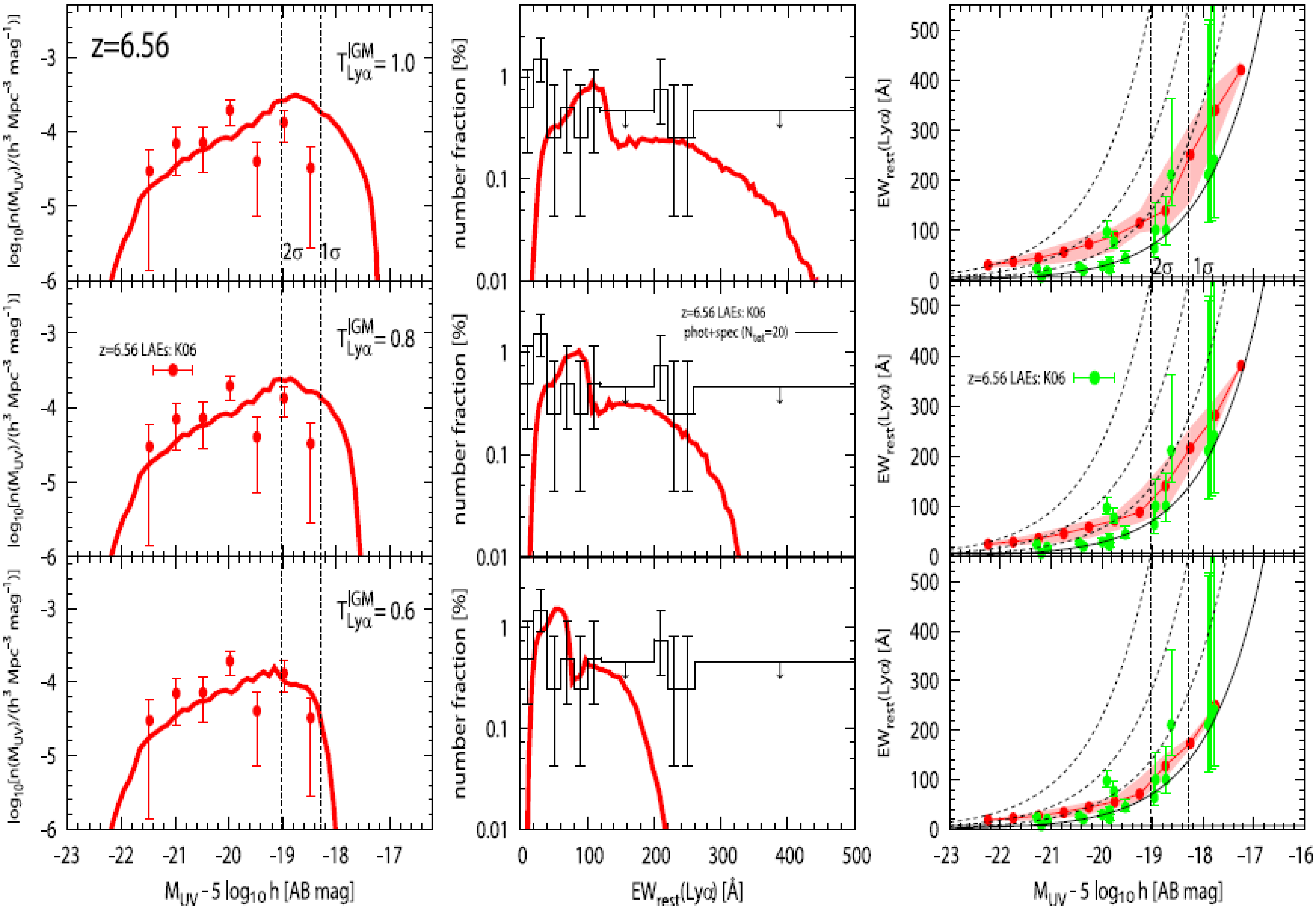


$$L^{obs}_{Ly\alpha} = L^{emit}_{Ly\alpha} T^{IGM}_{Ly\alpha}$$



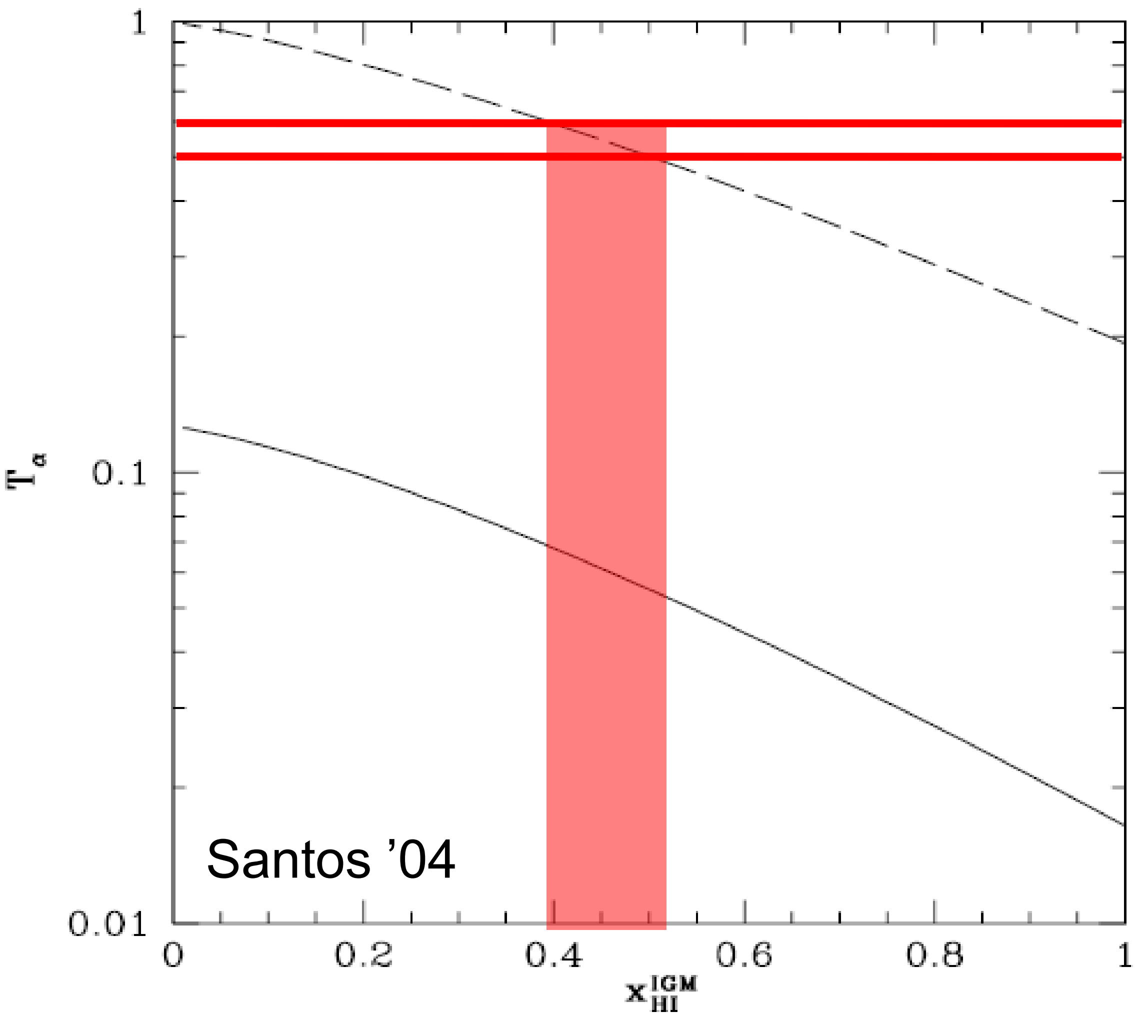
Lyα LF@z>6 can be reproduced if $T^{Ly\alpha}_{IGM}$ < 1 is adopted

OTHER OBS. QUANTITIES @ z > 6



IMPLICATION TO COSMIC REIONIZATION

□ $T^{IGM}_{Ly\alpha}(z=6.56) \sim 0.5\text{-}0.6$ ➔ $\langle x_{HI}(z=6.56)\rangle = ?$



- GRB050904@z~6.3
  ➔ x_{HI} (z~6.3) < 0.6
  (Totani+ '06)
- GP trough
  ➔ x_{HI} (z~6) > 10^{-3}
  (Fan+ '06)

$\langle x_{HI}(z=6.56)\rangle$
< 0.38－0.52