Semi-analytical model of high redshift galaxy luminosity functions

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with

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Modeling the formation rate of halos

- Analytical halo mass function in LCDM cosmology
- Press-Schechter halo mass function with Sasaki formalism :

$$N(M, z, z_c)\, \mathrm{d}M\, \mathrm{d}z_c = N_M(z_c) \left(\frac{\delta_c}{D(z_c)\sigma(M)} \right)^2 \frac{\dot{D}(z_c)}{D(z_c)} \frac{D(z_c)}{D(z)} \frac{\mathrm{d}z_c}{H(z_c)(1+z_c)}\, \mathrm{d}M$$

- $D(z_c)/D(z)$: probability that a halo collapsed at z_c survives till z

- Halo mass functions obtained from fitting N-body simulations : Sheth-Tormen (1999), Jenkins et al. (2001), Warren et al (2006), Reeds et al. (2003, 2007) etc.

- Problem : Analytic form of formation rate

- Derivative of the mass function : formation minus destruction rate at that epoch

Modeling the Star formation

- Star formation rate in a halo

$$\dot{M}_{\rm SF}(M, z, z_c) = f_* \left(\frac{\Omega_b}{\Omega_m} M\right) \frac{t(z) - t(z_c)}{\kappa^2 t_{\rm dyn}^2(z_c)} \exp\left[-\frac{t(z) - t(z_c)}{\kappa t_{\rm dyn}(z_c)}\right]$$

- UV luminosity is obtained from SFR by assuming some IMF and amount of dust reddening correction (η) : Hence $L_{UV} \propto f_*/\eta$
- The luminosity function

$$\Phi(M_{AB}, z)\, {\rm d}M_{AB} = \int_z^\infty {\rm d}z_c\, N(M, z, z_c) \quad \frac{{\rm d}M}{{\rm d}L_{1500}} \frac{{\rm d}L_{1500}}{{\rm d}M_{AB}}\, {\rm d}M_{AB}$$

- Self-consistent reionization/radiative feedback

Modeling the ionization history

- Evolution of average ionized hydrogen fraction f_{HII}

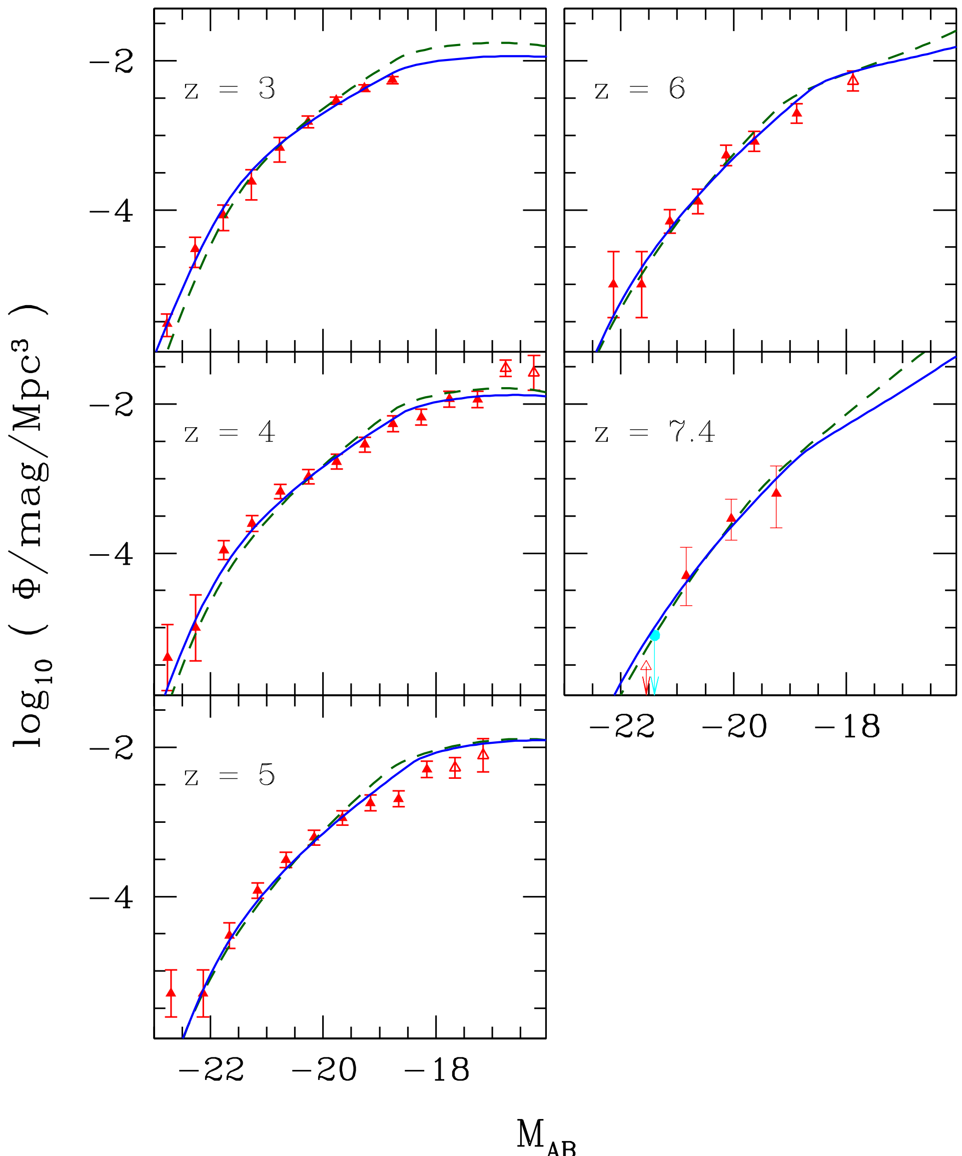
$$\frac{\mathrm{d}f_{HII}}{\mathrm{d}z} = \frac{\dot{N}_\gamma}{n_H(z)} \frac{\mathrm{d}t}{\mathrm{d}z} - \alpha_B n_H(z) f_{HII} C \frac{\mathrm{d}t}{\mathrm{d}z}$$

- Assumptions:
  - all the baryons are in the form of hydrogen
  - all the Lyman continuum photons that escape a star forming galaxy are used for ionization
  - Clumping factor C is defined as $C \equiv \langle n_H^2 \rangle / \bar{n}_H^2$
  - Case B recombination (α_B)
- The photon production rate is obtained from the SFR density using,

$$\dot{N}_\gamma = \frac{\dot{\rho}_{\mathrm{SF}}(z)(1+z)^3}{m_p} n_\gamma f_{esc}$$

UV luminosity function of LBGs

Samui, Srianand & Subramanian, 2007; Samui, Subramanian & Srianand, 2009



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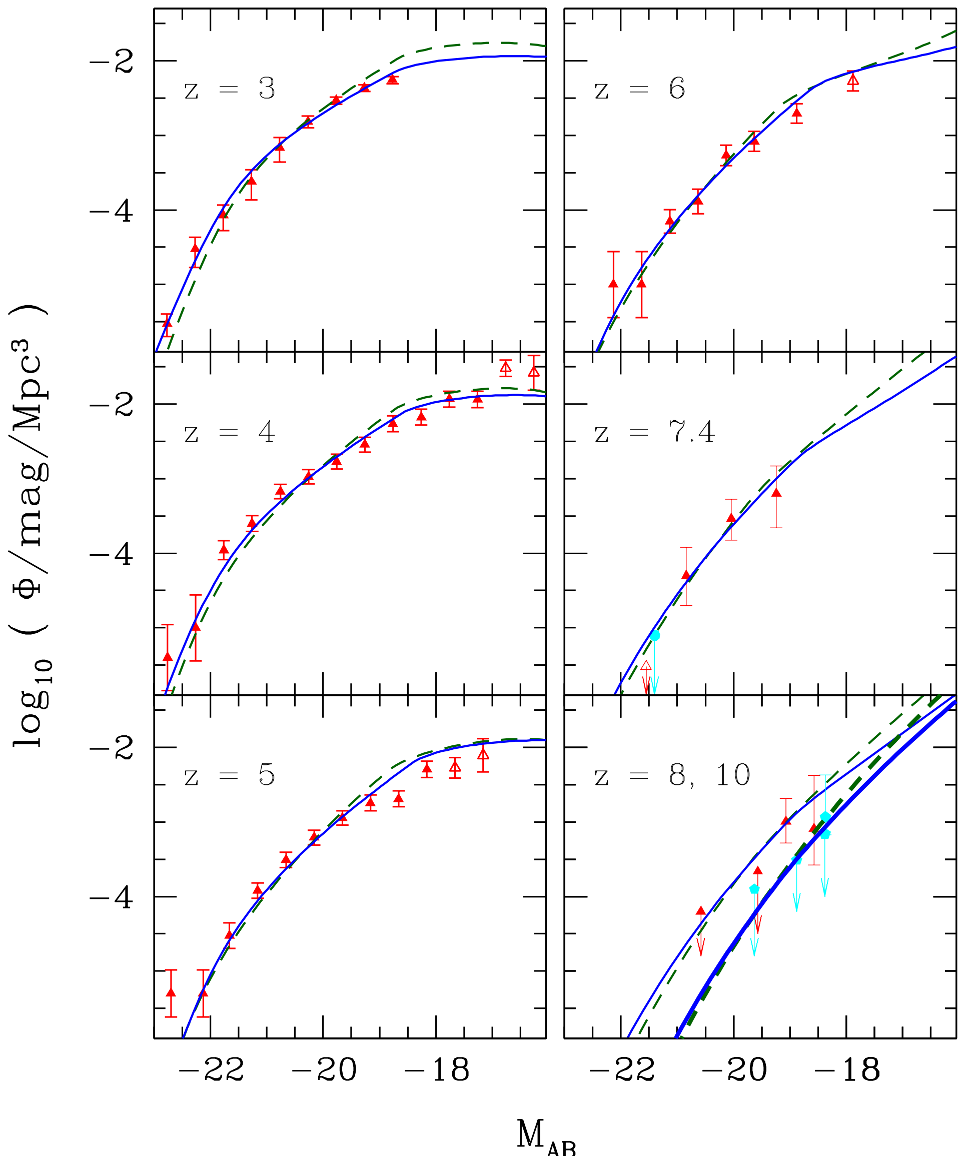


UV luminosity function : Results

- The redshift evolution of LF at $3 \leq z \leq 10$ can be explained as evolution in number density of halos coming from hierarchical structure formation model with a modest change in nature of star formation
- The redshift evolution of model parameters such as f_*, η depends on observed data set and form of halo mass function
- Sheth-Tormen halo mass function provides a better agreement compared to the Press-Schechter in terms of χ^2
- Decline SFR density at $z \lesssim 6$ is consistent with evolution only in number density of halos coming from structure formation
- Redshift evolution of LF in the low luminosity end can be used to constrain reionization history
- Small mass molecular cooled halos may be important for reionization but has not been detected in presently available observations

Luminosity of Lyman-α emitters

- Lyman-α luminosity emitted by a galaxy :

$$L_{Ly\alpha} = 0.68 h\nu_{\alpha}(1 - f_{\rm esc}) N_{\gamma} \dot{M}_{SF}$$

- Assumptions : Case B recombination
- The observed Lyman-α luminosity

$$L^{\rm obs}_{Ly\alpha} = f^{Ly\alpha}_{\rm esc} L_{Ly\alpha}$$

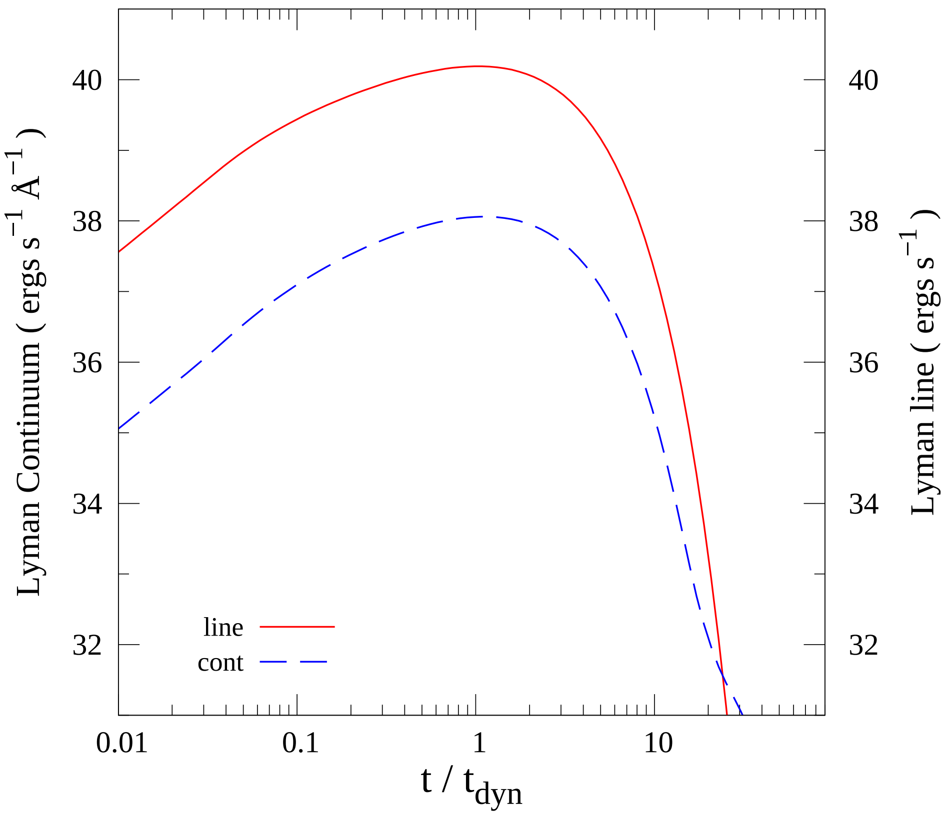
$$L^{\rm obs}_{Ly\alpha} \propto f^{Ly\alpha}_{\rm esc} f_{*}(1 - f_{\rm esc})$$

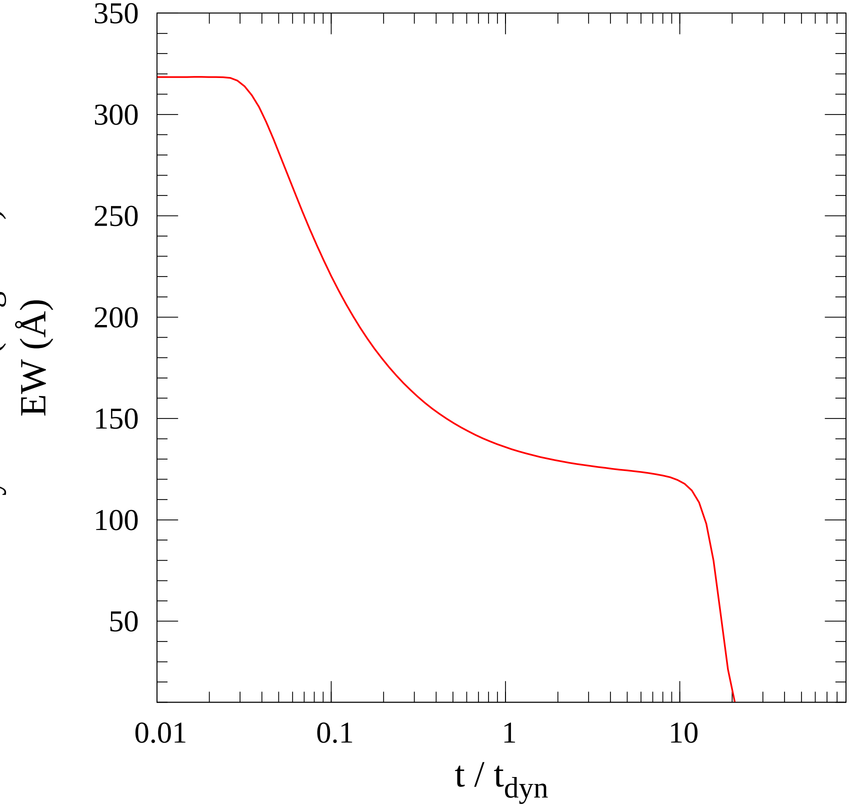
- The rest frame equivalent width of the Lyman-α emission

$$W_0 = L^{\rm obs}_{Ly\alpha}/(L_{cont}/\eta) = f^{Ly\alpha}_{\rm esc} L_{Ly\alpha}/(L_{cont}/\eta)$$

Samui, Srianand & Subramanian, 2009

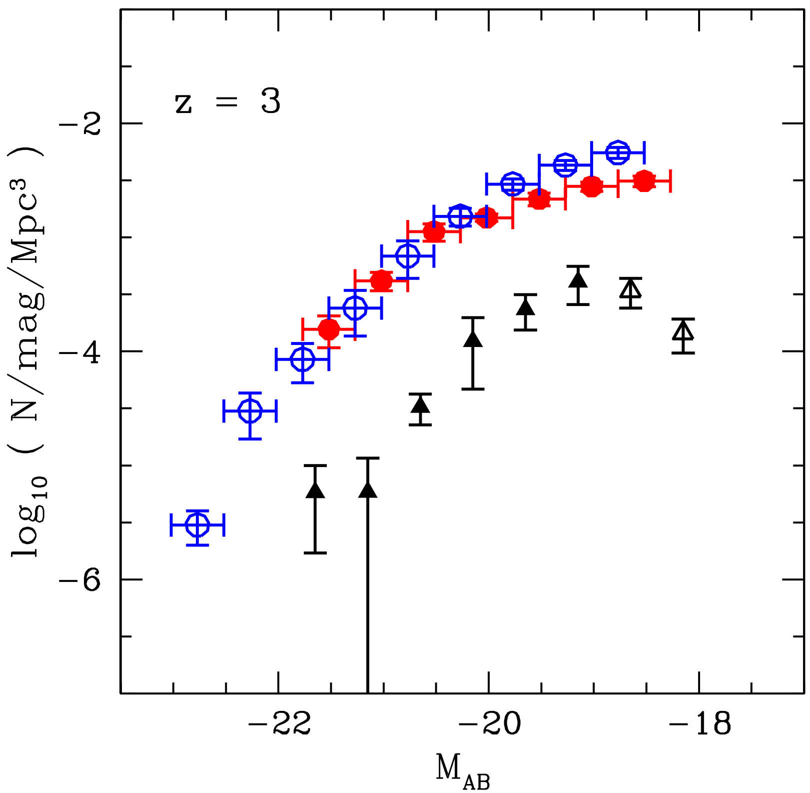
Luminosities and Equivalent width

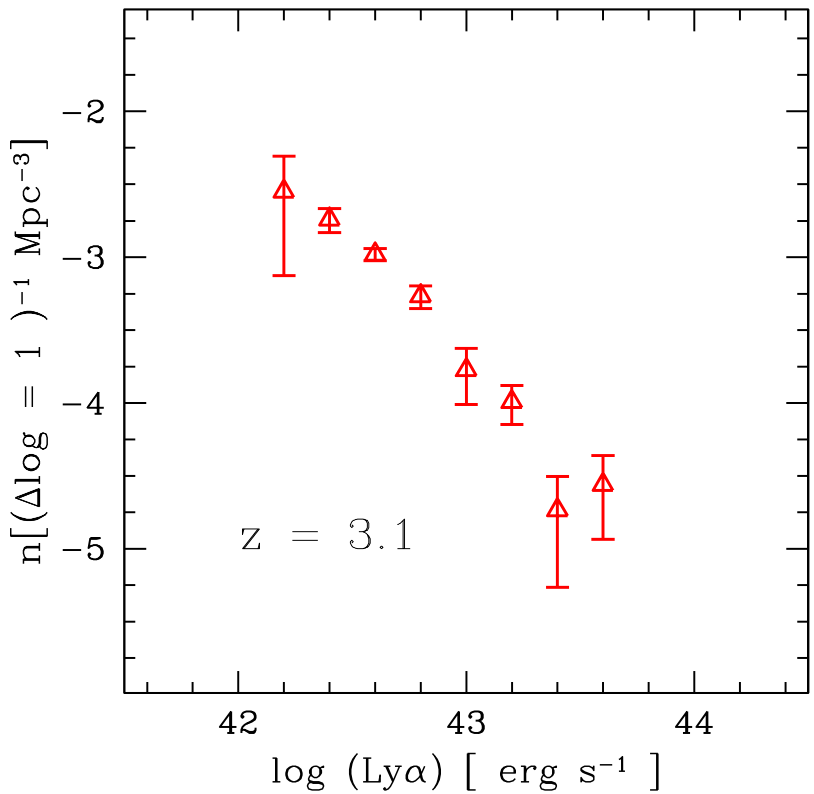




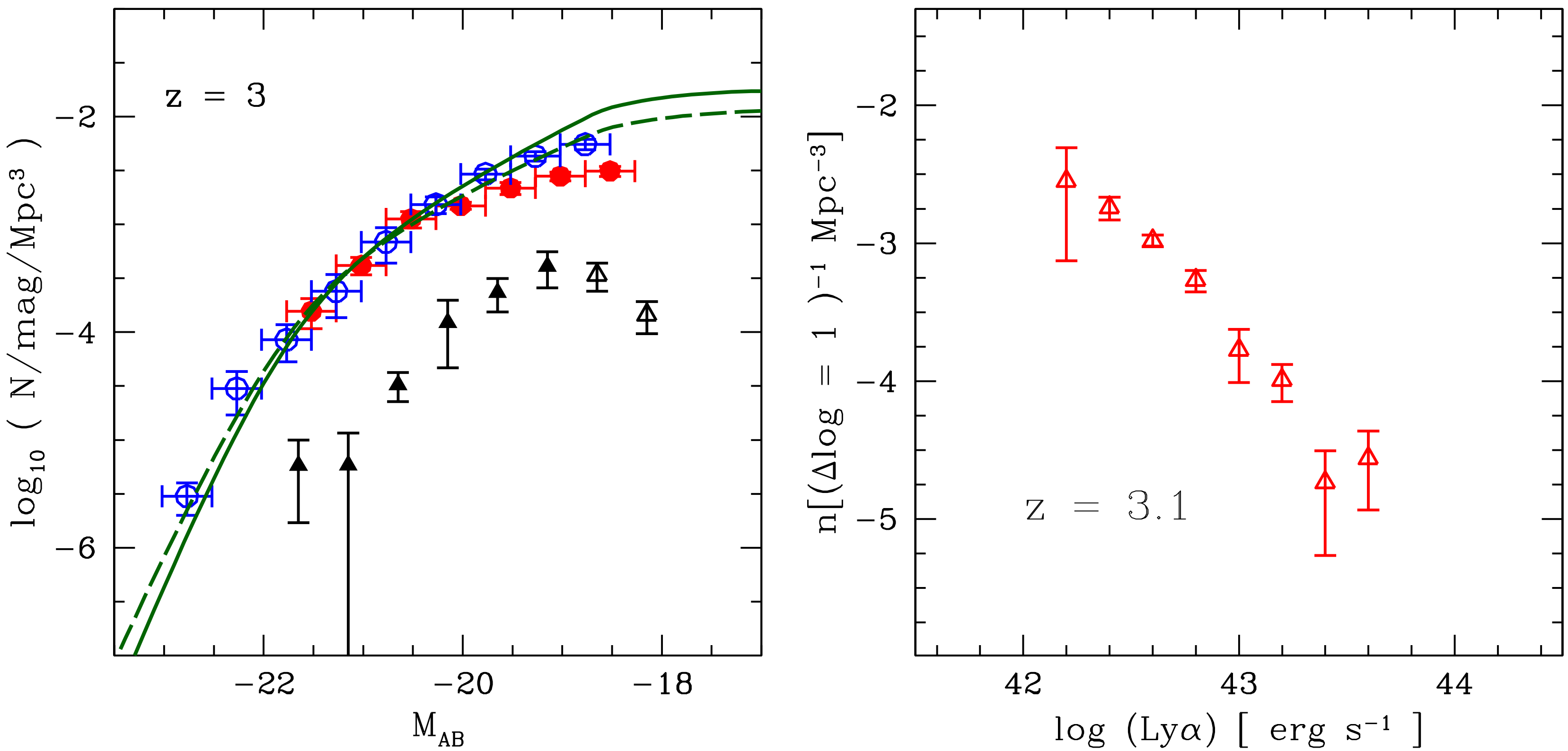
- Intrinsic equivalent width i.e. $f_{esc}^{Ly\alpha} = 1, \eta = 1$ with $f_{esc} = 0.1$
- Equivalent width is independent of halo mass

Observed luminosity functions of LAEs: $z \sim 3$





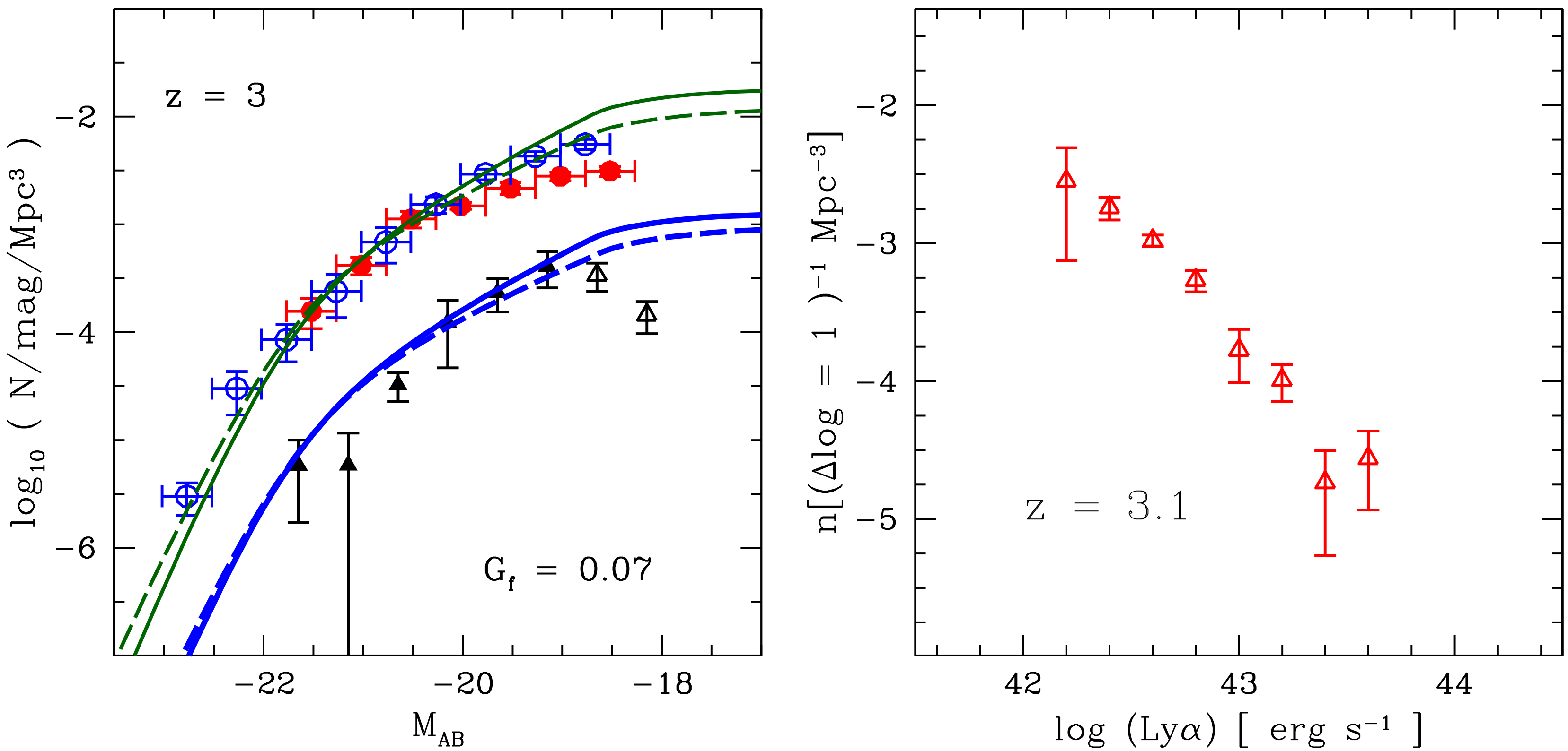
fit UV luminosity functions of LBGs: $z \sim 3$



PS $\Rightarrow f_*/\eta = 0.044$

ST $\Rightarrow f_*/\eta = 0.055$

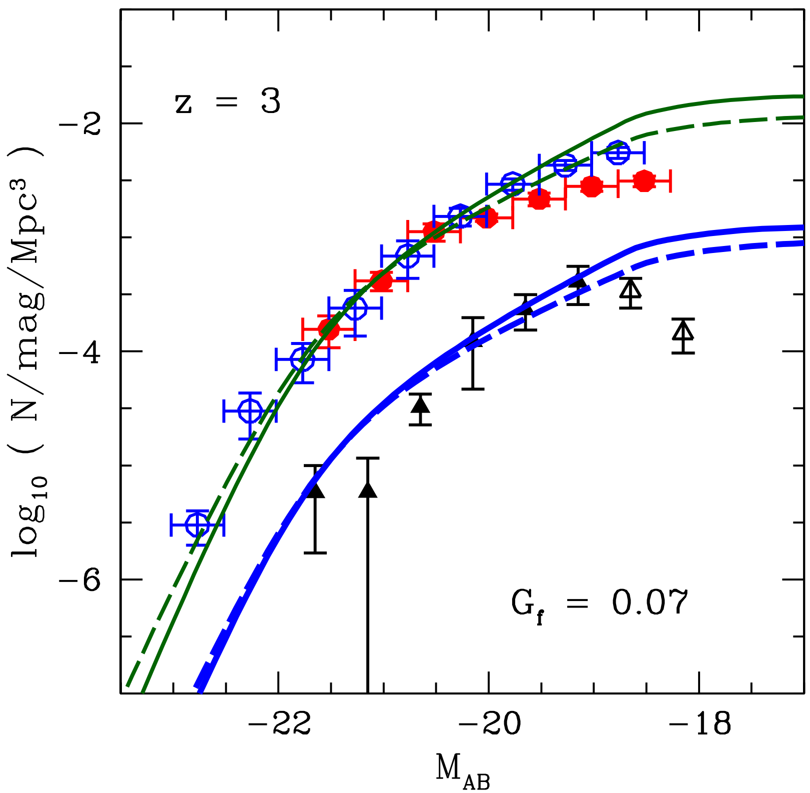
fit UV luminosity functions of LAEs: $z \sim 3$

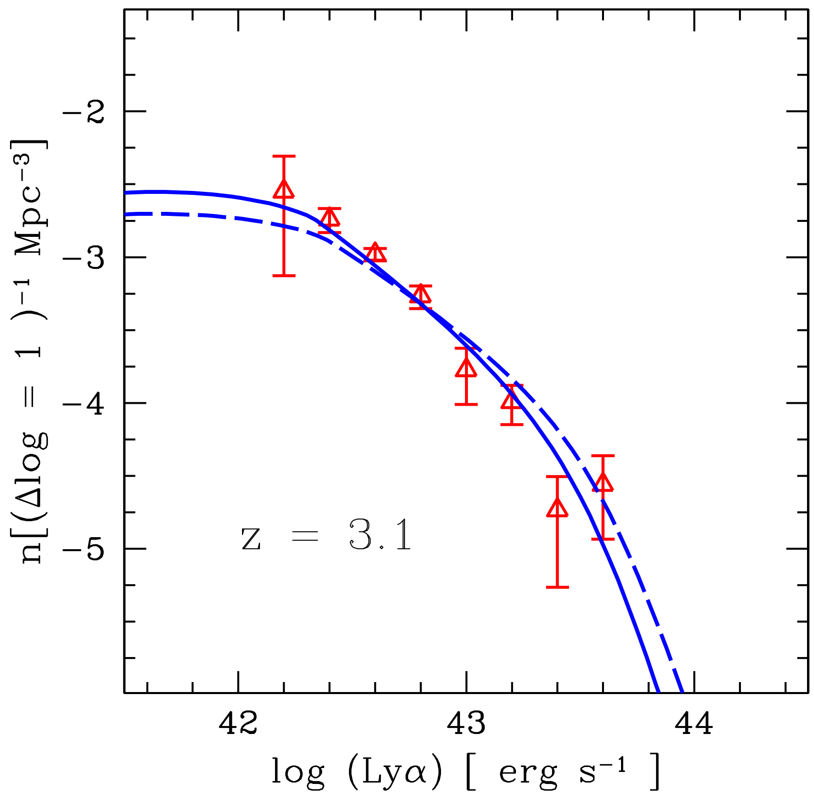


PS $\Rightarrow f_*/\eta = 0.044, G_f = 0.07$

ST $\Rightarrow f_*/\eta = 0.055, G_f = 0.07$

fit Lyman-α luminosity functions of LAEs: $z \sim 3$





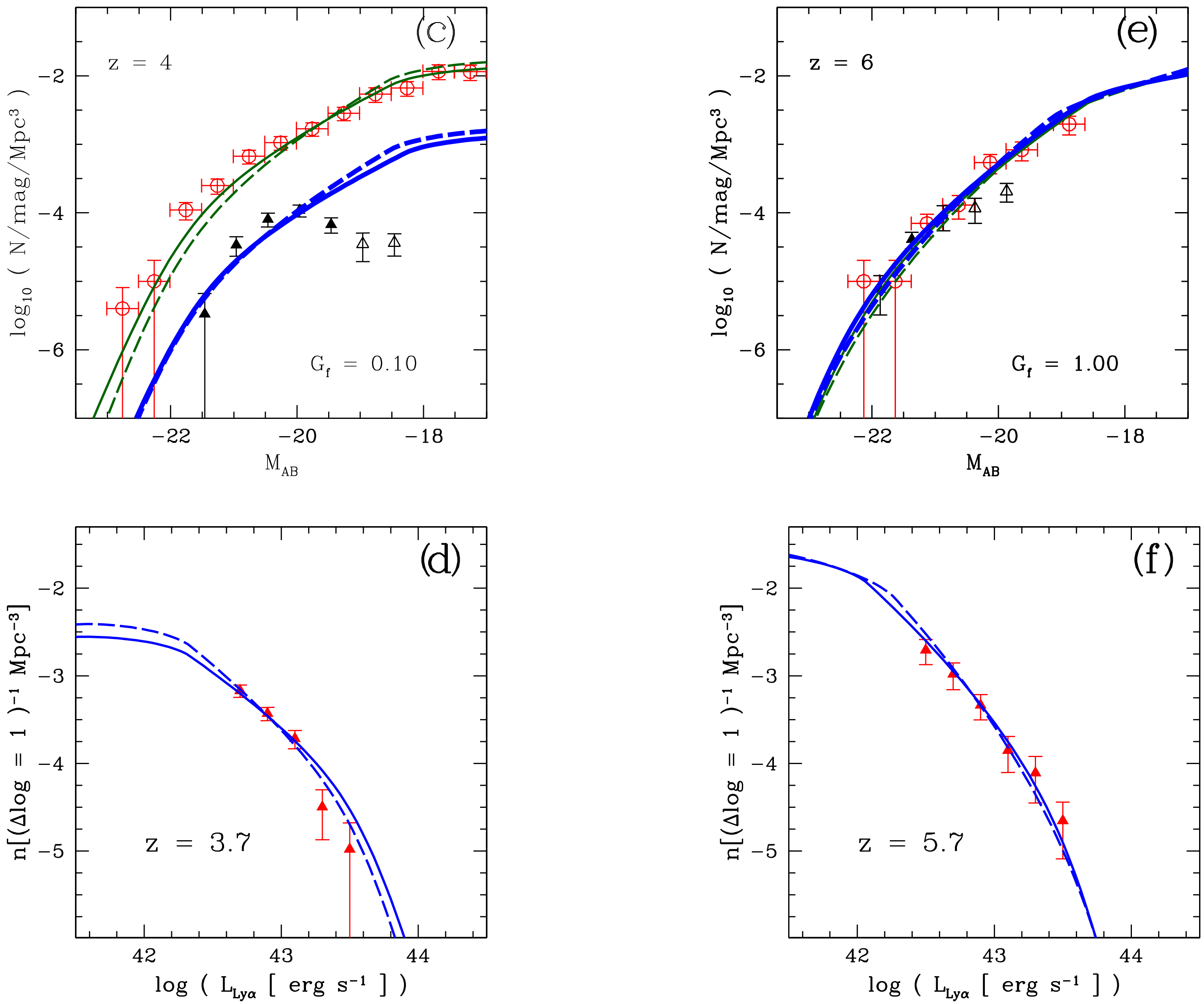
PS $\Rightarrow f_*/\eta = 0.044,\ G_f = 0.07$

ST $\Rightarrow f_*/\eta = 0.055,\ G_f = 0.07$

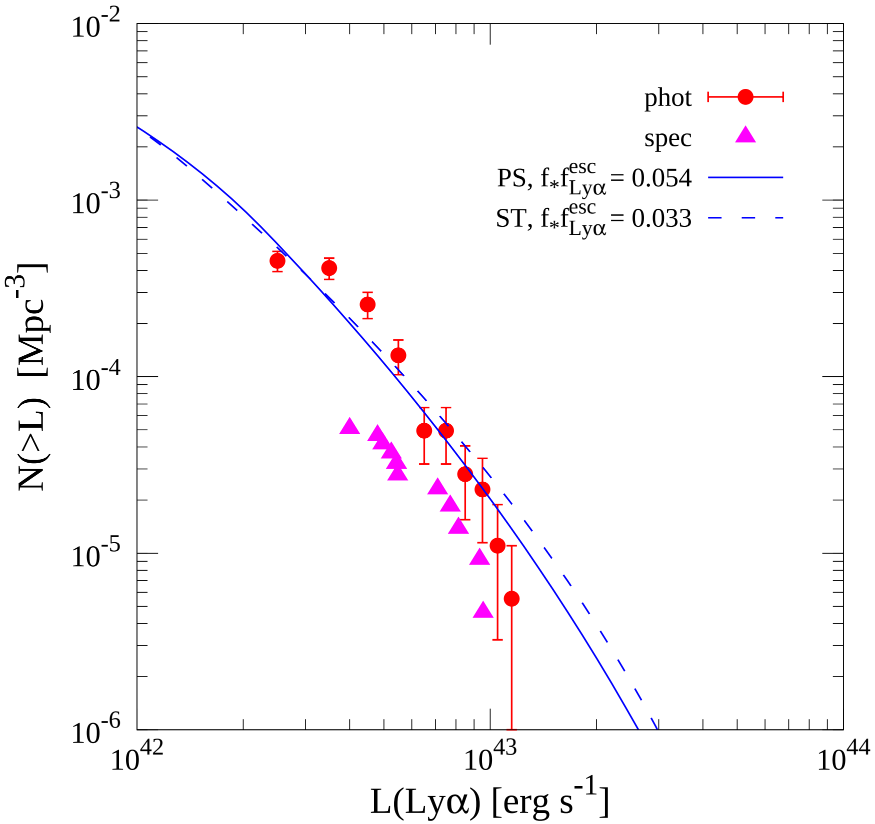
PS $\Rightarrow f_* f_{esc}^{Ly\alpha} = 0.059$

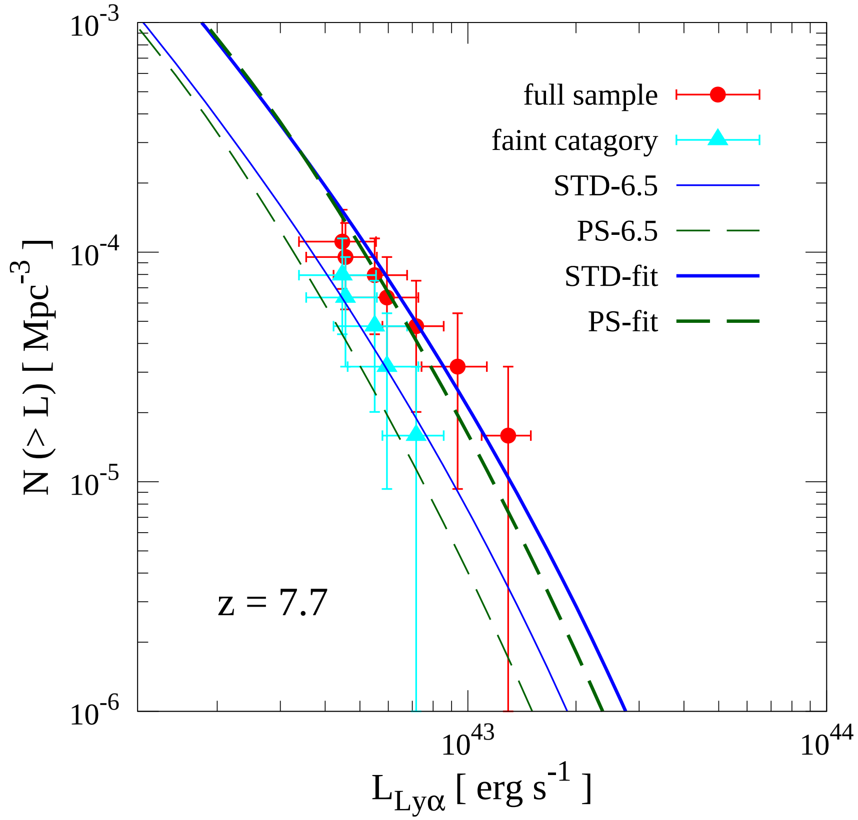
ST $\Rightarrow f_* f_{esc}^{Ly\alpha} = 0.076$

luminosity functions of LAEs: $z \sim 4$ & 6

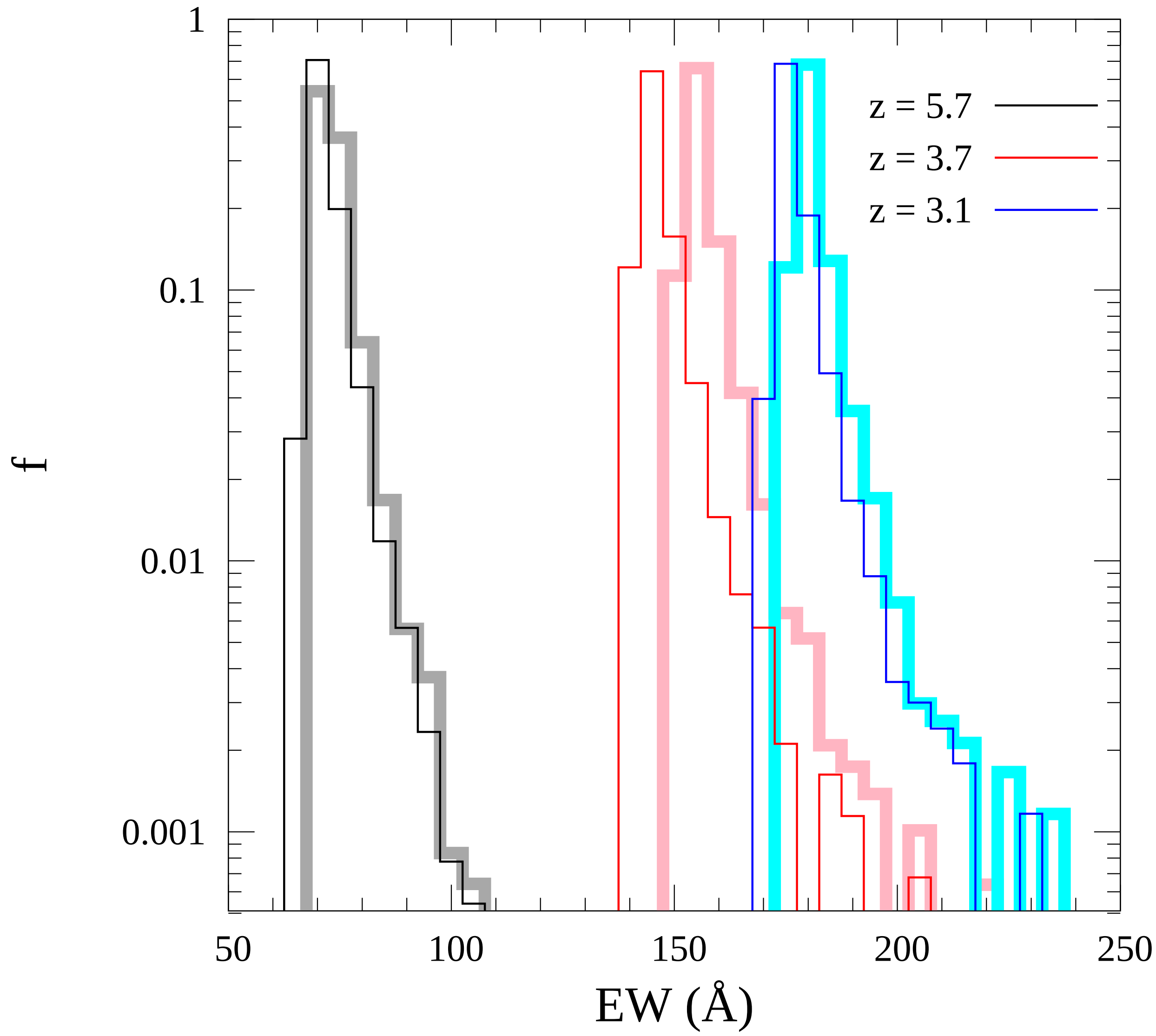


Cumulative LF at $z = 6.5$ & 7.7



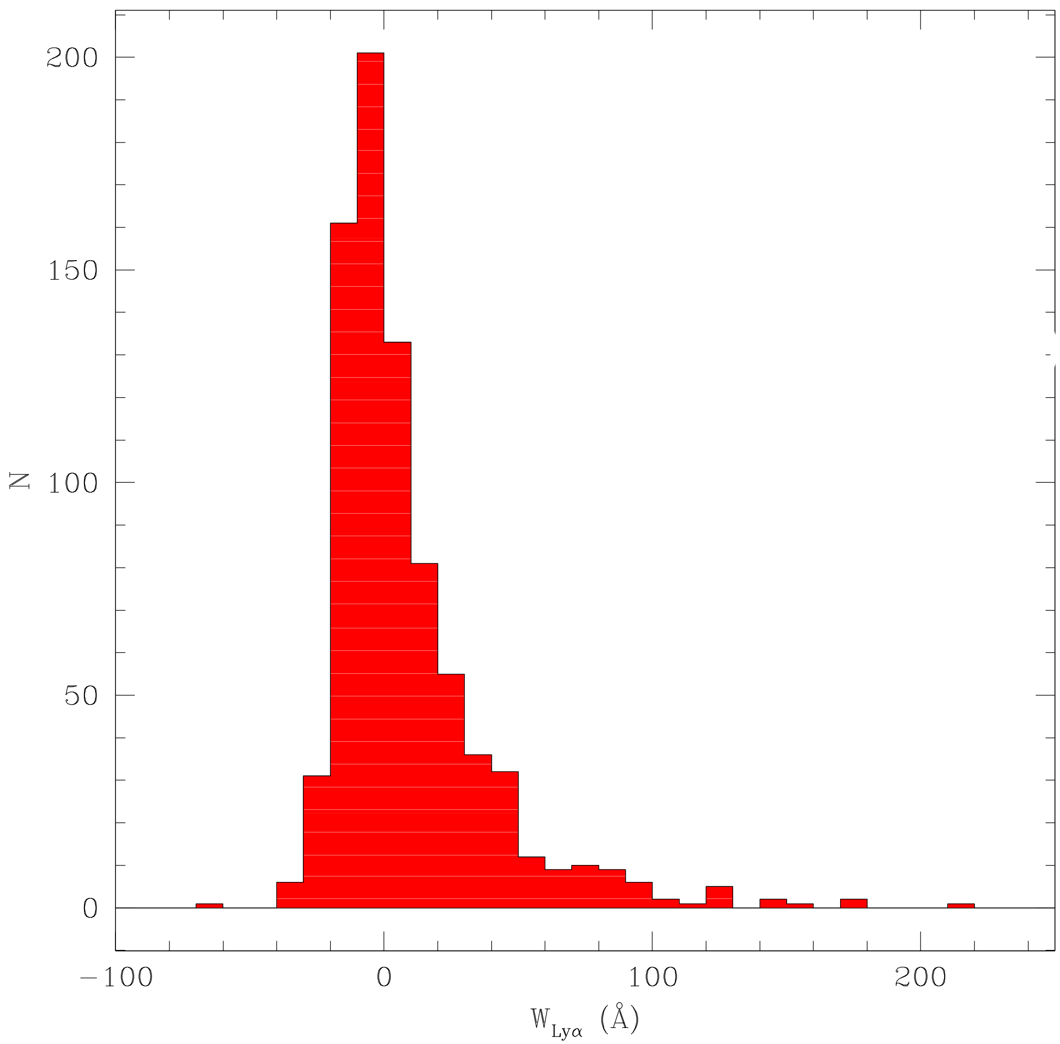


Evolution of equivalent width



Properties of LBGs at $z = 3$

Shapley et al. 2003



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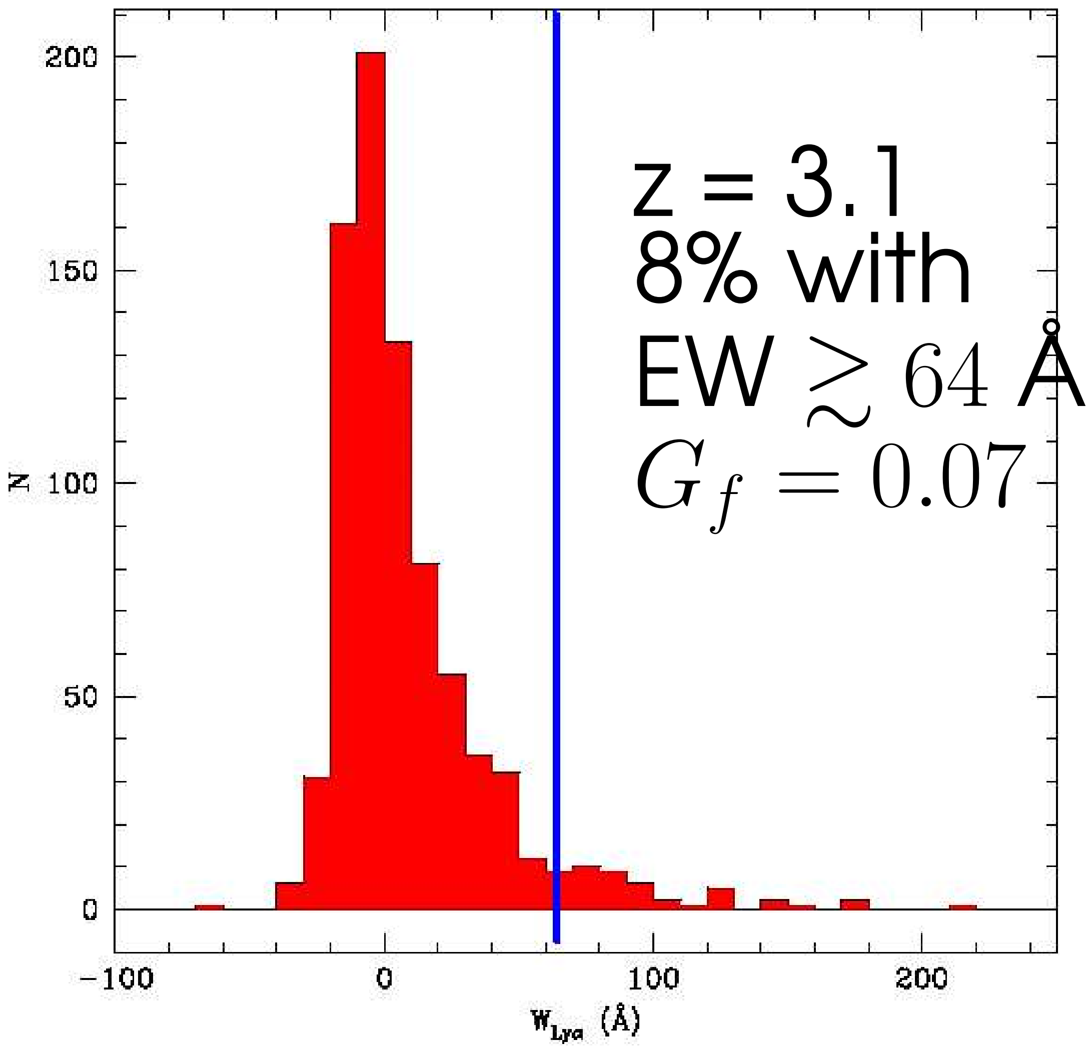

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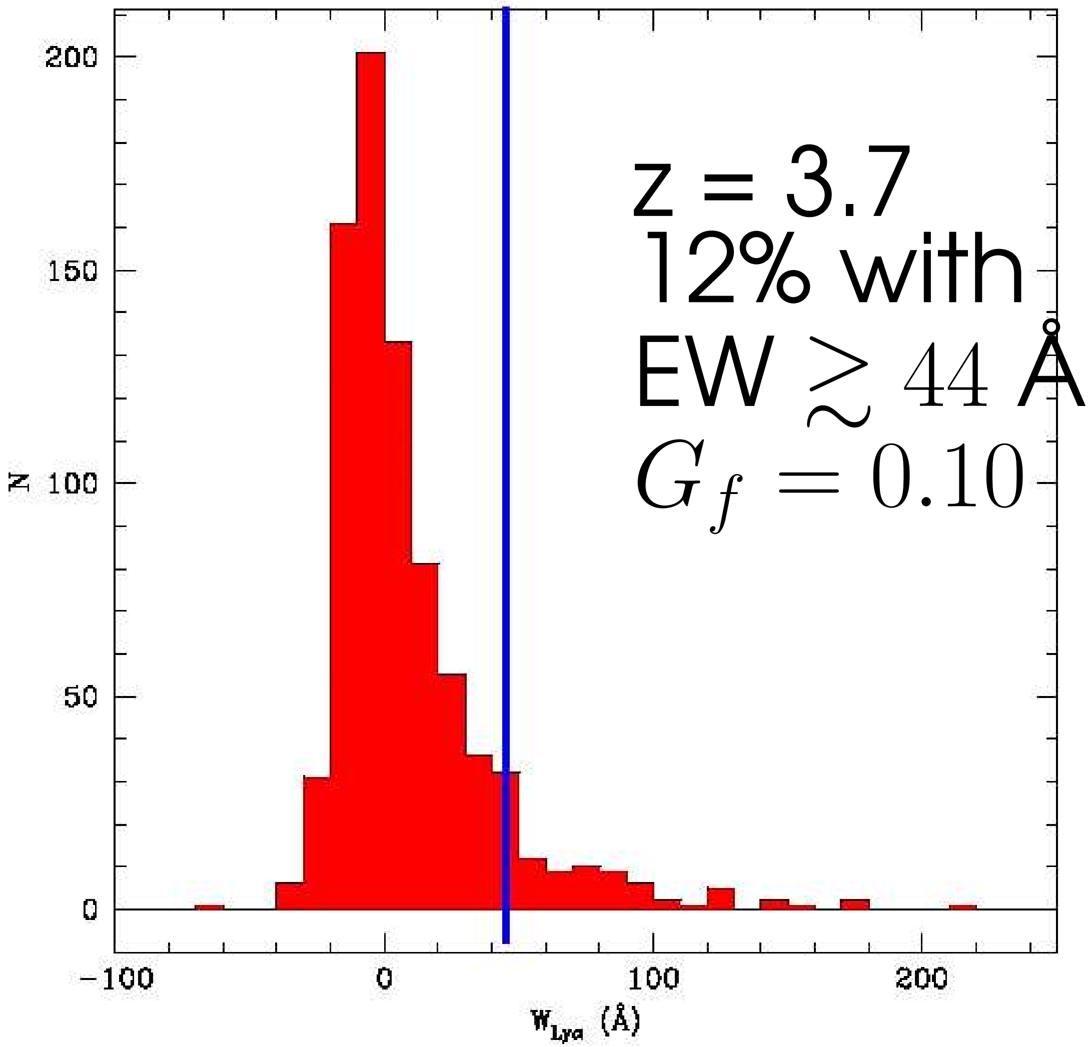

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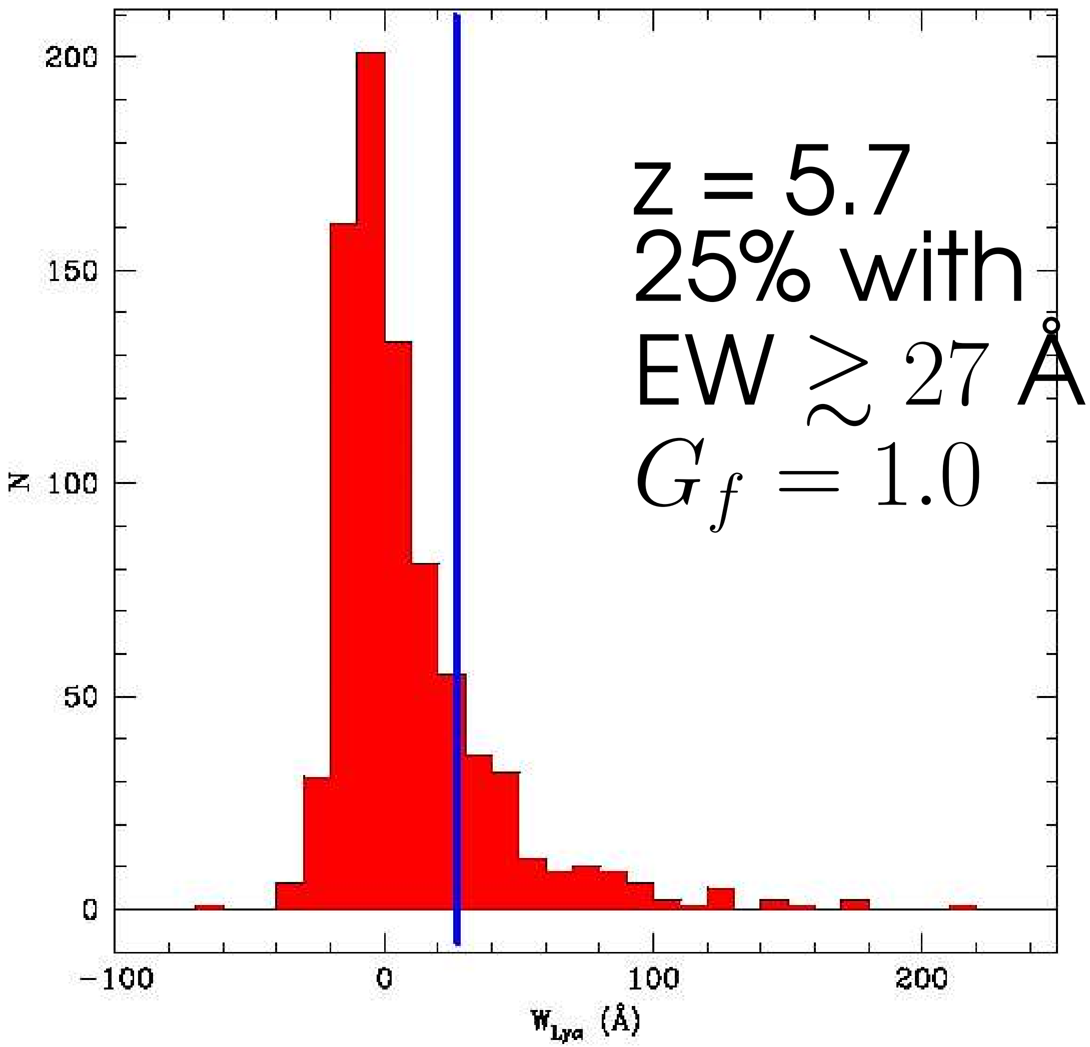

Conclusions on LAEs

- Semi-analytical model of star formation that explain the redshift evolution(?) of the LFs of LAEs
- Predicted fraction of LBGs that are LAEs (i.e. G_f) is consistent with observations of Shapley et al (2006) at $z = 3.1$
- G_f increases with redshift : Equivalent width cut-off?
- G_f should be 0.25 if no evolution in the escape of Lyman-α from $z \sim 3$ to $z \sim 6$
- The evolution in Lyman-α LF for $z \gtrsim 5.7$ is consistent with only halo number density evolution
- The evolution in $f_* f_{esc}^{Ly\alpha}$ is more for ST mass function compared to PS mass function
- Evolution in mean equivalent width with redshift

Thank you