Semi-analytical models of high redshift Lyman-α Emitters

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Simultaneous fit of UV and Lyman-α LFs of Lyman-α emitters and UV LF of LBGs at $3 \le z \le 6.5$

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MODEL

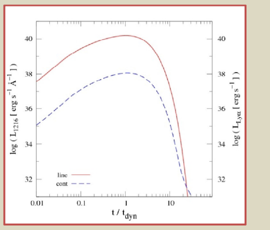
- We use Press-Schechter (PS)/Sheth-Tormen (ST) halo mass function in LCDM cosmology
- Star formation in a galaxy :

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

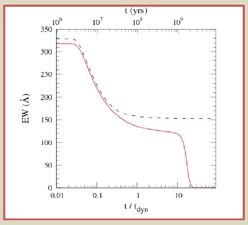
- "Starburst99" code has been used to get UV continuum luminosity and continuum near 1215Å
- The Lyman-α luminosity of a galaxy (case B recombination):

$$L^{obs}_{Ly\alpha} = f^{Ly\alpha}_{esc} L_{Ly\alpha} = f^{Ly\alpha}_{esc} \left[0.68 h\nu_\alpha (1 - f_{esc}) N_\gamma \dot{M}_{SF} \right]$$

- $h\nu_\alpha$ = 10.2 eV and f_{esc} = 0.1 are the energy of a Lyman-α photon and the escape fraction of UV ionizing photons; N_γ is the rate of ionizing photon production per unit solar mass of star formation
- $f^{Ly\alpha}_{esc}$ is the escape probability of the Lyman-α photons ; decided by the dust optical depth, velocity field of the ISM in the galaxies and the Lyman-α optical depth due to ambient intergalactic medium around the galaxies
- The rest frame equivalent width of the Lyman- emission : $W_0 = \frac{L^{obs}_{Ly\alpha}}{L_{cont}/\eta} = \frac{f^{Ly\alpha}_{esc} L_{Ly\alpha}}{L_{cont}/\eta}$
- $\eta \rightarrow$ dust reddening inside the galaxy for the continuum luminosity near 1215Å (L_{cont} :per unit wavelength)
- A subset (G_f) of all LBGs are Lyman-α emitters at any redshift



The time evolution of Lyman-α emission line luminosity at 1216 Å (solid line) and continuum flux near 1216 Å (dashed line) for 1 – 100 $M_\odot$ Salpeter IMF

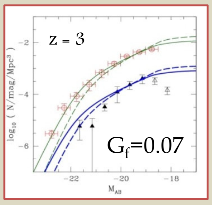


The time evolution of intrinsic Lyman-α equivalent width (W_0) of a galaxy as predicted by our models. Solid and dashed lines are for the Salpeter IMF in the mass ranges 1 – 100 $M_\odot$ and 10 – 100 $M_\odot$ respectively . We have assumed κ = 1, η=1. The dynamical time (t_{dyn}) depends on redshift of collapse (z_c). For example, at z_c = 10, 5 and 3, t_{dyn} = 8.8 × 10^7 , 2.2 × 10^8 and 4 × 10^8 yrs respectively. The actual time that corresponds to z_c = 10 is shown on the top axis.

RESULTS

At a particular redshift, we first fit the observed UV luminosity functions of LBGs by adjusting f_*/η using χ^2 minimization technique.
Then we fit the observed UV luminosity function of LAEs by changing G_f keeping same f_*/η (χ^2 minimization is not used due to scarcity of data and incompleteness problem).
Finally we match our model predictions with observed Lyman-α luminosity function at the same redshift by adjusting $f_{esc}^{Ly\alpha}$ and keeping G_f fixed.
Below we show these fits for both ST (solid curves) and PS (dashed curves) at different redshift.

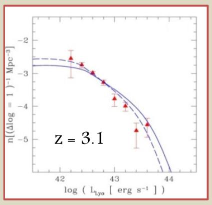
$z \sim 3$



UV LF of LBGs are from Reddy & Steidel (2008)
UV LF of LAEs are from Ouchi et al (2008)

PS ➧ $\frac{f_*}{\eta} = 0.044$, χ^2/dof = 3.90

ST ➧ $\frac{f_*}{\eta} = 0.055$, χ^2/dof = 0.90

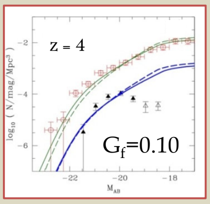


Lyα LF of LAEs are from Ouchi et al (2008)

PS ➧ $f_* f_{esc}^{Ly\alpha} = 0.059 \pm 0.011$, χ^2/dof = 0.95

ST ➧ $f_* f_{esc}^{Ly\alpha} = 0.076 \pm 0.011$, χ^2/dof = 2.49

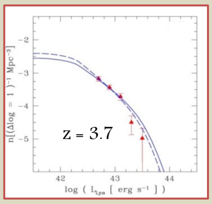
$z \sim 4$



UV LF of LBGs are from Bowens et al (2007)
UV LF of LAEs are from Ouchi et al (2008)

PS ➧ $\frac{f_*}{\eta} = 0.046$, χ^2/dof = 2.32

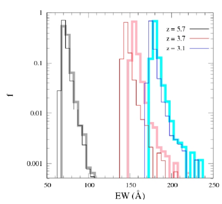
ST ➧ $\frac{f_*}{\eta} = 0.042$, χ^2/dof = 1.09



Lyα LF of LAEs are from Ouchi et al (2008)

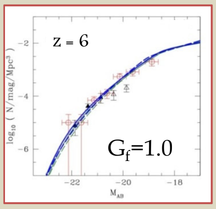
PS ➧ $f_* f_{esc}^{Ly\alpha} = 0.051 \pm 0.014$, χ^2/dof = 0.68

ST ➧ $f_* f_{esc}^{Ly\alpha} = 0.050 \pm 0.015$, χ^2/dof = 1.08



Distribution of Lyman-α equivalent width as predicted by our model at z = 3.1, 3.7 and 5.7. The thin lines are for the models that assume the PS halo mass function where as the thick lines are for the models with the ST mass function. Note that, here the spread in EW only comes from different ages of galaxies contributing to the luminosity function. In reality more spread is expected from the spread in values of η and $f_{esc}^{Ly\alpha}$.

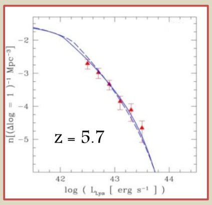
$z \sim 6$



UV LF of LBGs are from Bowens et al (2007)
UV LF of LAEs are from Ouchi et al (2008)

PS ➧ $f_* f_{esc}^{Ly\alpha} = 0.044 \pm 0.017$, χ^2/dof = 0.91

ST ➧ $f_* f_{esc}^{Ly\alpha} = 0.028 \pm 0.021$, χ^2/dof = 0.42

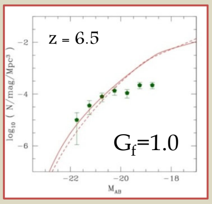


PS ➧ $f_* f_{esc}^{Ly\alpha} = 0.044 \pm 0.017$, χ^2/dof = 0.91

ST ➧ $f_* f_{esc}^{Ly\alpha} = 0.028 \pm 0.021$, χ^2/dof = 0.42

Lyα LF of LAEs are from Ouchi et al (2008)

$z = 6.5$



UV LF of LAEs are from Kashikawa et al (2006)

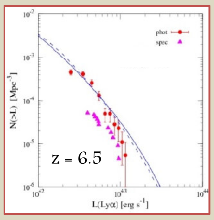
PS ➧ $\frac{f_*}{\eta} = 0.081$, χ^2/dof = – – –

ST ➧ $\frac{f_*}{\eta} = 0.050$, χ^2/dof = – – –

PS ➧ $f_* f_{esc}^{Ly\alpha} = 0.054 \pm 0.012$, χ^2/dof = 2.30

ST ➧ $f_* f_{esc}^{Ly\alpha} = 0.031 \pm 0.015$, χ^2/dof = 2.32

Lyα LF of LAEs are from Kashikawa et al (2008)



CONCLUSIONS

- ✓ At $z \le 4$ only 10% of LBGs are LAEs where as at z = 5.7 almost 100% of LBGs are LAEs
- ✓ No redshift evolution in the escape fraction of Lyman-α photons (less than 3σ) between z=3 to z=6.5
- ✓ For z > 6 LF of LAEs are consistent with evolution in halo mass function
- ✓ Average EW of LAEs decreases with redshift