A Physical Model of Lyman-Alpha Emitters

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Abstract : We present a simple physical model for populating dark matter halos with Lyα emitters, and predict the physical properties of LAEs at z≈3-7. The central idea of our model is that the Lyα luminosity of LAEs is proportional to the star formation rate (SFR) which is directly related to the halo mass accretion rate, rather than its total mass. The efficiency of star-formation is the only free parameter in our model.

Our model predicts a constant star-formation efficiency and reproduce Lyα luminosity functions & other physical properties including stellar ages, SFRs, stellar masses and clustering properties of LAEs at z≈3-7. We conclude that the LAEs are powered by the accretion of new material, and relating the mass accreted by the halos, instead of the total mass, to the Lyα luminosty of LAEs naturally gives rise to the duty cycle of LAEs predicted by some earlier studies.

Physical Model

The Lyα luminosity

$$L_{Ly\alpha} = 1\times10^{42} \times \frac{SFR}{M_{\odot}\ yr^{-1}}$$

The star-formation rate

$$SFR = f_* \times \left(\frac{\Delta M_{gas}}{t_{Ly\alpha}}\right) = f_* \times \left(\frac{\Delta M_b}{t_{Ly\alpha}}\right) = f_* \times \dot{M}_b$$

The stellar mass

$$M_* \approx SFR \times t_{Ly\alpha} \approx f_* \times \dot{M}_b \times t_{Ly\alpha} = f_* \times \frac{\Omega_b}{\Omega_{DM}} \times \Delta M_{DM}$$

where f_*, ΔM_{gas}, $t_{Ly\alpha}$=30 Myrs, ΔM_b, and ΔM_{DM} are the star-formation efficiency, gas accreted by halos, an average age of stellar populations in LAEs, the baryonic mass and the dark matter mass accreted by the halos, respectively.

Assumptions :

- approximate escape fraction of Lyα photons and ionizing Ly-continuum photons be unity and zero, respectively.
- a constant universal ratio of baryons to dark matter (DM).

Methodology :

- populate all DM halos, in a cosmological simulation, with LAEs having their Lyα luminosities proportional to the halo mass accretion rate.
- construct the Lyα LF at z=3.1
- compare this model Lyα LF with the observations at z=3.1 to obtain the best-fit parameter (star-formation efficiency).
- use this constant star-formation efficiency at all other redshifts, z≈3-7 to construct Lyα LFs at these redshifts.

Results

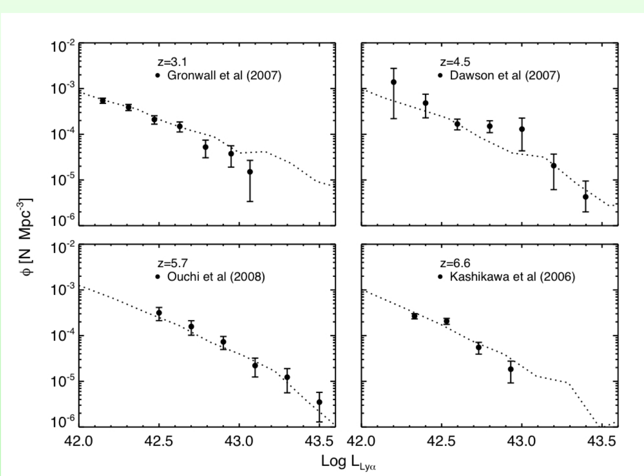

Fig. 1 : Comparing model and observed Lyα luminosity functions at z≈3-7.

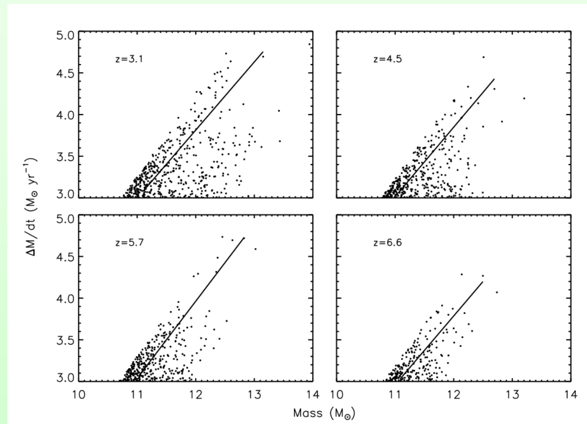

Fig. 2 : Halo mass accretion rate as a function of halo mass. A constant slope (~0.8-0.9) at z≈3-7 implies that there is no evolution of SFRs and other physical properties of LAEs at these redshifts. In addition, it also implies that the mass accretion rate is a non-linear function of halo mass.

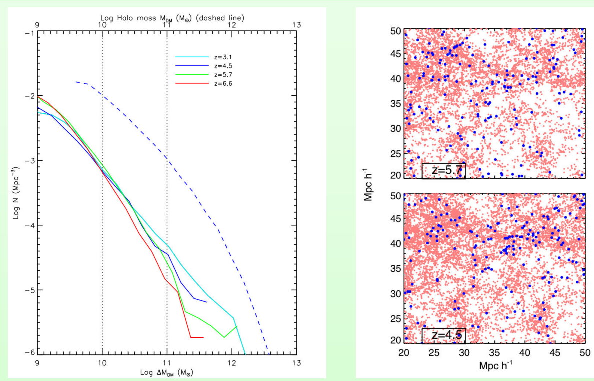

Fig. 3 : ***Left panel*** : Number density of halos as a function of mass accreted (solid lines) and as a function of total halo mass (dashed blue line).

Right panel : Spatial distribution of our model LAEs (blue filled circles) with Ly-alpha luminosity > 2×10^{42} ergs s^{-1} superimposed on distribution of dark matter halos (red filled circles) at z=5.7 (top right) & z=4.5 (bottom right). Note that different halos host LAEs at different redshifts giving rise to the duty cycle of LAEs quite naturally.

Conclusions

- This simple model reproduces the primary physical properties of LAEs at z≈3-7.
- The star-formation, and hence Lyα emission in LAEs is powered by the accretion of new material.
- Our model predicts a constant star-formation efficiency of 2.5% at all redshifts, in agreement with the values derived using completely different approach (e.g. Fukugita et al 1998, Baldry et al 2008).
- The model LAEs have stellar ages≈30 Myrs, stellar masses~10^7-$10^8 M_{\odot}$, and SFRs≈1-10 $M_{\odot} yr^{-1}$, in good agreement with the observations (e.g. Finkelstein et al 2007, Gawiser et al 2007, Pirzkal et al 2007).
- Relating mass accreted by halos, rather than the total mass, gives rise to the duty cycle of LAEs (e.g. Nagamine et al 2008) quite naturally.
- We also find that our model LAEs have correlation lengths ≈3-6 h^{-1} Mpc, and show a field variance ≈30% for a volume limited (≈2×10^5 Mpc^3) and flux limited surveys.

References

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