A Model Prediction to the Nature of high-z Lyman Alpha Emitters

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INTRODUCTION

Lyman Alpha Emitter (LAE)

LAE is one of the most important galaxy pop. because of the following two reasons. (1) detecting redshifted Lyα emission with narrow-band filter is a powerful strategy to seek for high-z galaxies (e.g., Iye+06), and (2) they can be used as a probe of cosmic reionization because the strength and profile of Lyα emission could significantly be affected by IGM HI.

OBSERVATIONAL DATA OF LAE

The nature of LAE pop. and connection with other high-z galaxy pop. (e.g., LBG) have been poorly understood. However, their statistical quantities (i.e., Lyα & UV luminosity functions (LFs), EW(Lyα) distributions) have been more firmly established because of the increase of survey fields and available samples (e.g, Ouchi+08, 10).

Important information about LAE can be obtained through comparisons between the observed statistical quantities and theoretical models of LAE.

PREVIOUS THEORETICAL MODELS FOR LAE

There are several theoretical models for LAE in the framework of hierarchical galaxy formation with different approaches: analytic (e.g, Thommes & Meisenheimer05), cosmological hydrodynamic sim. (e.g., Nagamine+08), and semi-analytic model (SAM; e.g., Orsi+09).

However, in all of them, the escape fraction of Lyα photons from their host galaxy ($f_{esc}^{Ly\alpha}$) is oversimplified, although it is the most important ingredient: constant regardless any phys. prop. of galaxy, or the same amount with that for continuum photons. These assumptions are clearly inconsistent with the implications from observations (e.g., Kunth+98) and theoretical results from radiative transfer for Lyα photons (e.g., Hansen & Oh06).

OUR MODEL FOR LAE

Our model (Kobayashi+07,10; KTN07,10) is a unique one because the following two effects are incorporated into $f_{esc}^{Ly\alpha}$ for the first time: (1) interstellar dust extinction, whose strength is not necessarily the same with that for UV continuum and (2) galactic outflow induced as a feedback of supernova (SN).

It has been shown that (1) all of the available observational data for Lyα & UV LFs and EW distributions of LAEs @ z=3-6 are reproduced well, and (2) those of LAEs @ z > 6 indicate IGM neutral fraction (x_{HI}) rapidly evolves from $x_{HI}(z<6)$ << 1 into $x_{HI}(z>6)$ ~ 1.

AIM OF THIS RESEARCH

Recently, the phys. prop. of LAE begin to be constrained observationally via stellar pop. analysis (e.g., Nilsson+07, 10; Finkelstein+09; Ono+10). However, these constraints are limited to continuum-bright LAE. Because LAE continuum is typically faint, it is fair to say the phys. prop. of typical LAE are not well constrained yet.

Here we present our model prediction to the phys. prop. of LAE and examine the origin that discrete LAE (i.e., EW ≧ 20 A) and non-LAE (i.e., EW < 20 A).

MODEL DESCRIPTION

Model of Galaxy Formation

Our model is based upon a SAM, *“Mitaka model”* (Nagashima & Yoshii 04). It analytically computes merger history of DM halos based on ΛCDM, and then follows the evolution of baryons trapped in halos by using phenomenological models. As a result, the Mitaka model provides all of the physical quantities (e.g., SFH, Z, $M_\star$, dust amount) of galaxies at any redshift.

Extensions for LAEs

We developed a phenomenological model for $f_{esc}^{Ly\alpha}$ which is physically motivated by both of theoretical and observational studies. The effects of interstellar dust extinction and galactic wind are incorporated as the following way:

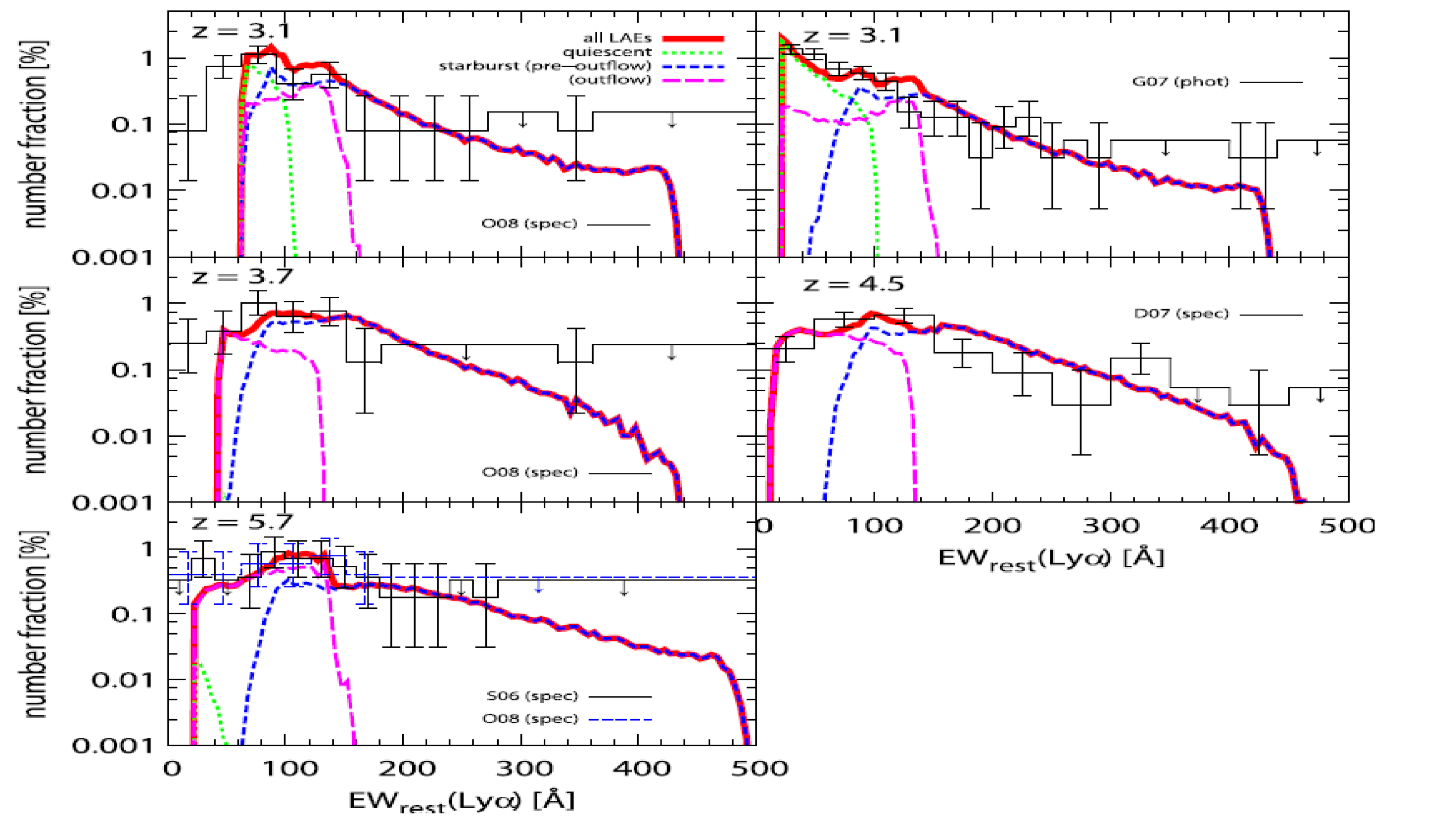
$$f_{esc}^{Ly\alpha} = f_0 \frac{1-\exp(-\tau_d^{Ly\alpha})}{\tau_d^{Ly\alpha}}, \quad \tau_d^{Ly\alpha} = \frac{N_{cold}Z_{cold}}{(N_{cold}Z_{cold})_0^{Ly\alpha}} \quad \ldots \text{ quiescent \& pre-outflow starburst}$$

$$f_{esc}^{Ly\alpha} = f_0^{wind} \quad \ldots \text{ outflow starburst}$$

f_0, $(N_{cold}Z_{cold})_0^{Ly\alpha}$, and f_0^{wind} are free parameters, which has been determined by obs. Lyα LF at z=5.7 (Shimasaku+06). $(N_{cold}Z_{cold})_0^{Ly\alpha}$ controls the strength of extinction for Lyα and this parameter can be different from that for UV continuum photons, which has already been determined by the Mitaka model.

By using the parameter values fixed via the observed Lya LF of the LAEs at z=5.7, our model nicely reproduces all of the available observed data (i.e., Lyα and UV LFs, EW distribution; see Fig.1) at z=3-6.

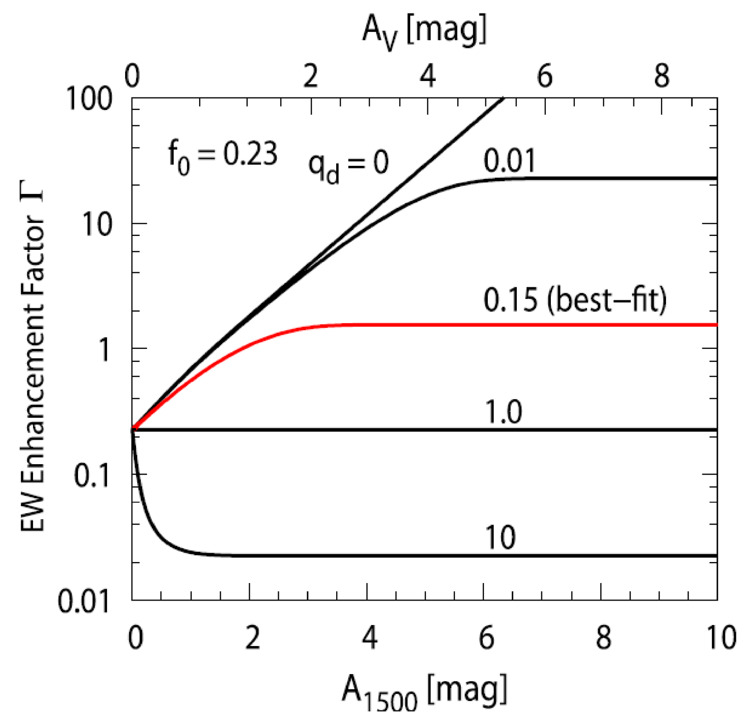
Those at z > 6 are also reproduced if the IGM transmission for Lyα is decreased by a factor of ~ 0.6 compared to that at z < 6. This is consistent with the observational constraints to the cosmic reionization.



[Fig.1] Rest-frame EW distribution for LAEs at z=3-6 (Fig. 5 of KTN10). The curves are predictions by our model, while the histograms are the obs. data. The contributions from quiescent, pre-outflow phase starburst, and outflow phase starburst are plotted separately. Here, we select model LAEs by the same criteria of $L_{Ly\alpha}$ and EW as those adopted in each observation.

Implication to Dust Geometry of LAE ISM

The best-fit value of $(N_{cold}Z_{cold})_0^{Ly\alpha}$ indicate dust extinction of Lyα is less effective than that of UV continuum ($\tau_d^{Ly\alpha} / \tau_d^{cont} = 0.15$), implying a clumpy dust distribution in ISM of LAE. The selective extinction for continuum leads to boost of EW. The enhancement factor Γ, which is defined as $\Gamma = EW^{obs} / EW^{int}$, depends on dust extinction as shown in the Fig. 2. As a result, our model predicts a POSITIVE correlation among EW and dust extinction.



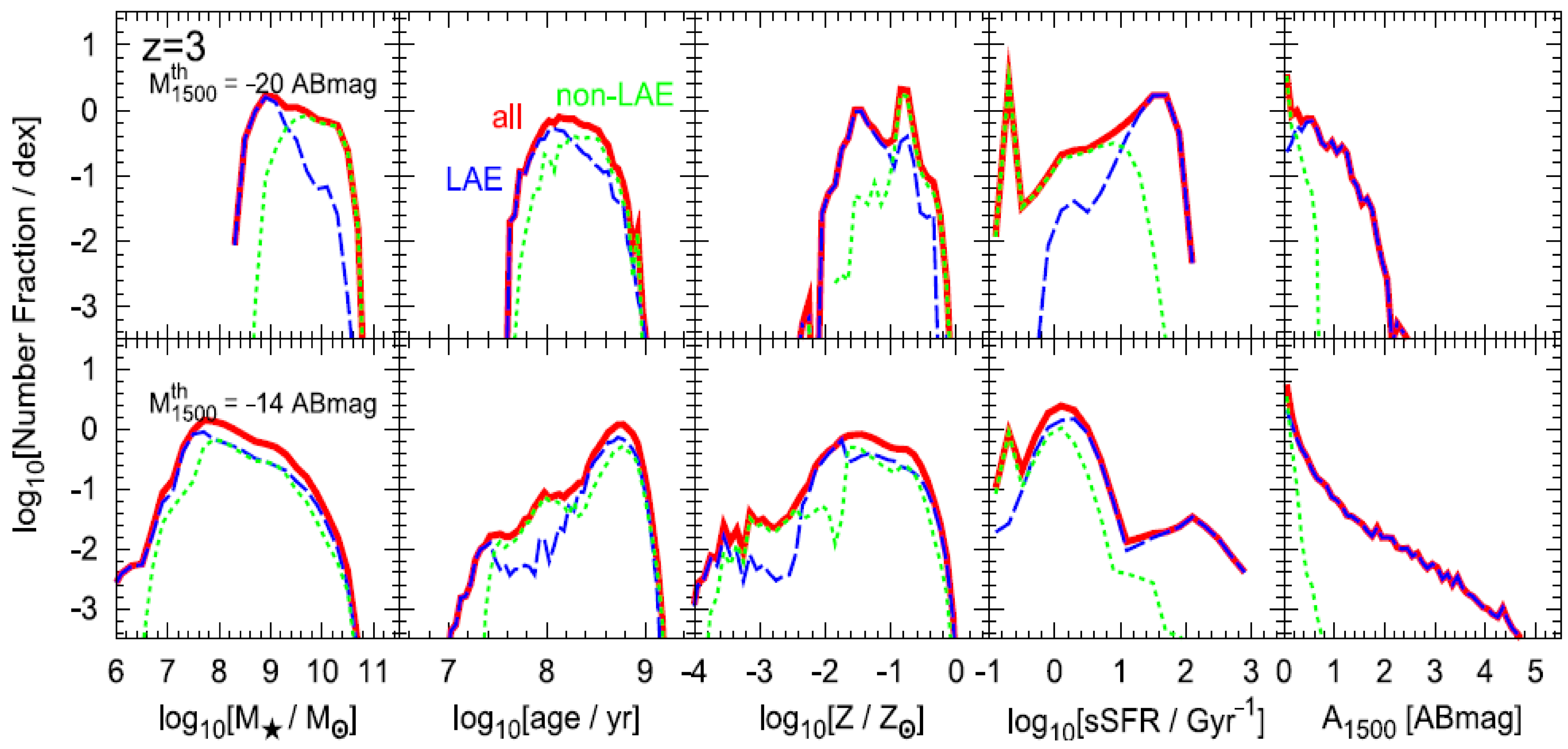
$$\Gamma = \frac{f_0}{q_d} \frac{1-\exp[-q_d \tau_d^c(\lambda_{Ly\alpha})]}{1-\exp[-\tau_d^c(\lambda_{Ly\alpha})]}.$$

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

[Fig.2] EW enhancement factor Γ as a function of extinction mag. at 1500 A, A_{1500}, or V-band, A_V (Fig.1 of KTN10). Γ for several values of q_d (q_d=0-10) is shown, while f_0 is fixed to be 0.23 (our best-fit value).

RESULTS

We show model predictions to the phys. prop. of LAE and non-LAE at z=3, for example. Here, model galaxies with $M_{1500} - 5\log h \leqq M_{1500}^{th}$ (= -20 or -14 ABmag) are picked out. The former M_{1500}^{th} is reachable of the present obs., while the latter is much fainter than the present limit. We do not give any criteria neither for $L_{Ly\alpha}$ nor UV cont. color. Hence, some galaxies (both LAE and non-LAE) may not be selected as LBG observationally because of their too red UV cont. slope.



[Fig.3] Predicted distributions of phys. prop. of the galaxies at z=3. Red, blue, and green curves are those for all galaxies, LAE, and non-LAE, respectively. From left to right, distributions of $M_\star$, mass-weighted age, Z, sSFR, and A_{1500} are shown. Top and bottom panels are for M_{1500}^{th} = -20 and -14 ABmag, respectively.

Model predictions to $M_\star$, age, and Z at M_{1500}^{th} = -20 mag are consistent with a classical picture for LAE; LAE is less-massive, younger and metal-poorer than non-LAE. On the other hand, those at M_{1500}^{th} = -14 mag are similar among LAE and non-LAE. LAE has wide ranges of $M_\star$ ($\log[M_\star/M_\odot]$ ~ 7-10), age (~10 Myr - 1 Gyr), and Z (~ 0.01-1 $Z_\odot$). For these prop., LAE is not a peculiar pop. in all of the star-forming galaxies at the redshift.

Predictions to the sSFR and A_{1500} dist. are quite different among LAE and non-LAE. LAE has higher sSFR and larger A_{1500} than non-LAE. Higher sSFR leads to brighter intrinsic $L_{Ly\alpha}$ and larger EW^{int}, which does not depend on any model prescription. Higher A_{1500} boosts EW more significantly, which is attributed to our result of clumpy dust geometry.

DISCUSSIONS & CONCLUSION

We find that LAE is not a single pop. of young starburst with less massive and dust-free and its $M_\star$, age, and Z of LAE are very diverse. This is consistent with the recent observational results (e.g., Ono+10).

Our model suggests that the necessary conditions to be LAE are high sSFR and large A_{1500}. This result is considerably attributed to clumpy dust geometry. However, we do not consider it is an unique solution to fit all of obs. data consistently.