★ Ultraviolet and Infrared Radiation from Protogalaxies ★

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Abstract

Solving three dimensional radiative transfer, we study the escape fraction of ionizing photons from LAEs and LBGs.
As a result, we find the LAEs and LBGs allow a high escape fraction (17%~47%) and can ionize the intergalactic medium(IGM) at z=3~5 (Yajima et al. 2009).
We also study infrared property of LAEs and LBGs solving absorption energy by dust and dust temperature, and show the evolution of IR luminosity and IR spatial structure (Yajima et al. in preparation).

Model & Method

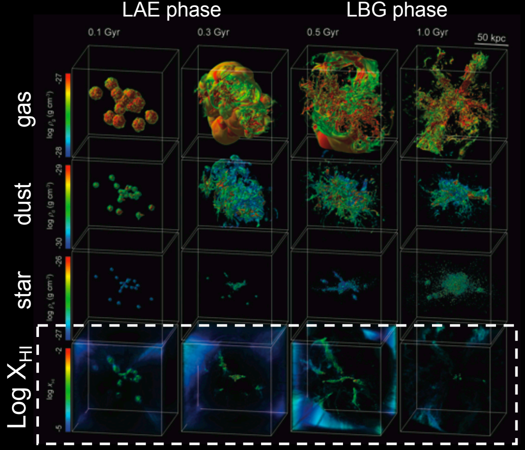
- Model galaxies : Mori & Umemura (2006)
(AUSUM DV + N body simulation in isolated system)
- Box size in our simulation : 128^3 cells

- 3D radiation transfer simulations (ART method)
- Ionization structure of hydrogen with equilibrium state
- Estimation of escape fraction of ionizing photons
- Dust temperature with radiation equilibrium

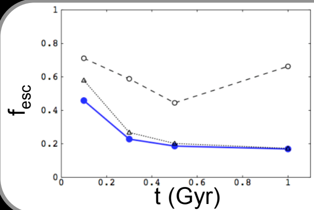
Escape fraction

$$f_{esc} = \frac{N^{\gamma}_{escape}}{N^{\gamma}_{intrinsic}}$$

Ionization structure

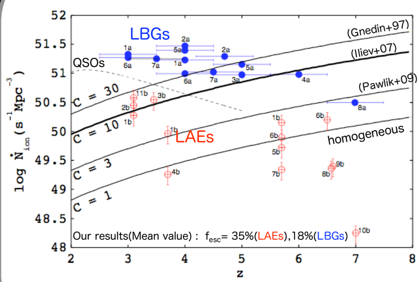


Escape fraction of ionizing photons



Escape fractions f_{esc} for the simulated galaxy as a function of evolutionary time. Blue symbols represent the f_{esc} with dust extinction. Black open circles denote f_{esc} without dust extinction. The black open triangles show the dust sputtering model.
The f_{esc} decreases with galaxy evolution. The dust can change the f_{esc} by factor ~2.

Can LAEs and LBGs ionize IGM?



Necessary photon number to ionize the IGM(black lines)

$$N_{ion}(z) = 10^{47.4} C\,(1+z)^3 \mathrm{s^{-1}Mpc^{-3}}$$

(Madau et al. 1999)

Radiated photon number by LAEs an LBGs

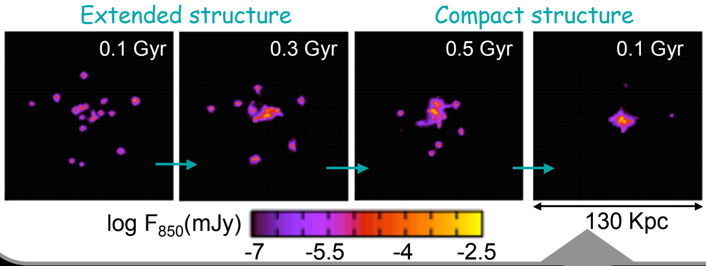
$$N_{ion}(z) = \left(10^{53.1}\mathrm{s^{-1}Mpc^{-3}}\right) \times SFRD(z) \times f_{esc}$$

Observation data — Our results

LAEs(b)		LBGs(a)
1: Ouchi+08	8: Kodaira+03	1: Steidel+99
2: Kudritzki+00	9: Taniguchi+05	2: Yoshida+06
3: van_Breukelen+05	10: Iye+06	3: Iwata+05
4: Fujita+03	11: Gronwall+07	4: Bowens+06
5: Ajiki+03		5: Ouchi+04
6: Malhotra+04	Observation data	6: Sawicki+06
7: Rhoads+03	(SFR density)	7: Gabash+04
		8; Ouchi+10

→LBGs can ionize IGM at z=3-6.

850 μm image



The 850 μm flux distribution of model galaxies in observed flame. We assume that the model galaxies distribute at z=3. The sub-mm structure evolves from extended to compact with galaxy evolution.

Dust model

Density : 3 g/cm^3 (silicate)

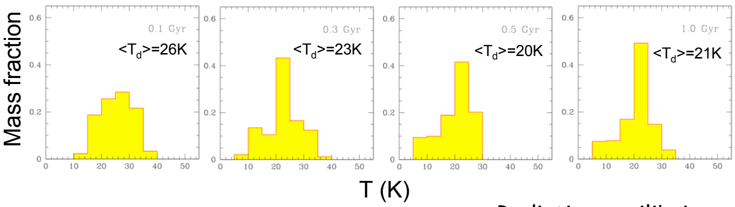
Size : $0.1\mu m \sim 1.0\mu m$ (Nozawa+06)

Distribution function : $n_{dust}(a_d) \propto a^{-3.5}$ (Mathis+77)

$Q-value$: $Q(\lambda)=1$ (Draine+84)

$m_{dust} = 0.01\frac{Z}{Z_{sun}} m_H$ (Draine+07)

Dust temperature

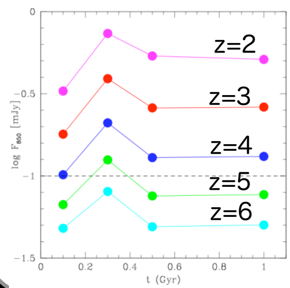


Dust temperature decreases with galaxy evolution.

Radiation equilibrium

$$\iint 4\pi J_\nu Q(a,\nu)\pi a_d^2 n_d\, da\, d\nu = \iint 4\pi a_d^2 B_\nu(T_d) Q(a,\nu) n_d\, da\, d\nu \sim 4\pi \bar{a}_d^2 \bar{n}_d \bar{Q}\,\sigma T_d^4$$

Detectability with ALMA



Total flux of 850 μm at the observed flame as a function of evolution time. The flux is estimated by observing over all surface of the model galaxies. We assume the model galaxies distribute at each redshift. Dash line is detection limit of ALMA with 1 hour. We suggest that LAEs and LBGs at z<5 can be detected by ALMA with 1 hour.

Summary

1: LAEs and LBGs can have a large escape fraction(17% ~ 47%).
2: LBGs can ionize the IGM at z = 3 - 5. However, only LAEs and LBGs cannot ionize the IGM at z > 6.
3: The spatial distribution of sub-mm shows extended structure at LAE phase, and compact structure at LBG phase.
4: LAEs and LBGs at z < 5 can be detected with ALMA.

Reference :
Razoumov A. O., & Sommer-Larsen J., 2010, ApJ, 710, 1239
Gnedin N. Y., Kravtsov, A. V., & Chen, H. -W., 2008, ApJ, 672, 765
Wise J., Cen R., 2009, ApJ, 693, 984
Mori M., & Umemura M., 2006, Nature, 440, 644
Yajima H., Umemura M., Mori M., Nakamoto T., 2009, MNRAS, 398, 715
Yajima H., Choi J. -H., Nagamine K., arXiv:1002.3346