Formation and Evolution of Lyman-alpha Emitters

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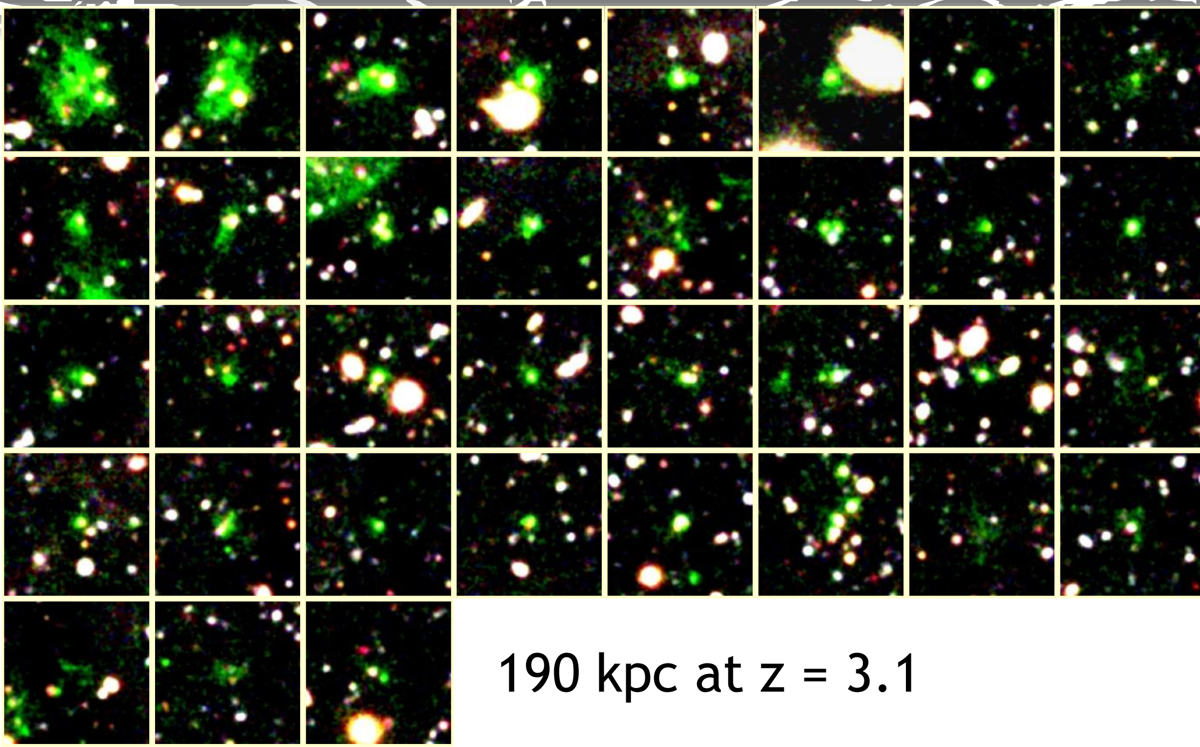
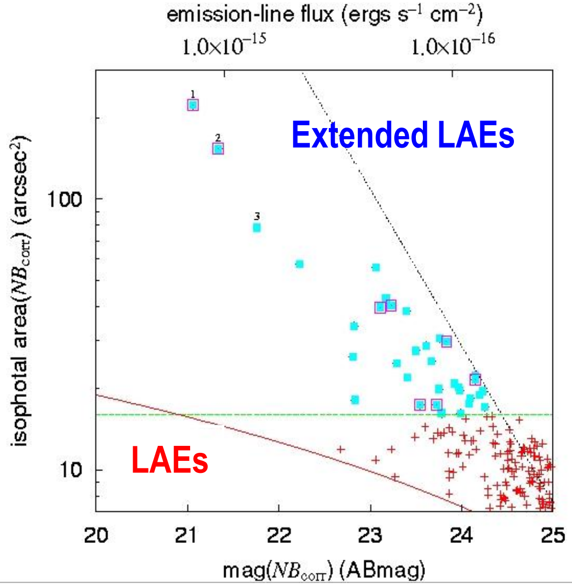
Presentation Outline

- Dynamical and chemical evolution of LAEs
- Star formation histories of LAEs with different masses
- Emission process of Lyman alpha photons
- Escape fraction of ionizing photons from LAEs and LBGs and reionization of the universe
- Infrared dust emission from LAEs and LBGs

Images of Bright Lyman Alpha Emitters (LAB: Lyman Alpha Blobs)



190 kpc at z = 3.1



Matsuda et al., AJ, 128, 569 (2004)
observed the 35 extended Lyα emitters in and around the SSA22a field at z=3.1.

- The luminosity range of Lyα emission is 6×10^{42} to 10^{44} erg s^{-1}.
- They have bubble-like features, and filamentary and clumpy structures.
- <u>One third of them are apparently not associated with UV continuum sources that are bright enough to produce Lyα emission.</u>

Three-dimensional Hydrodynamic Model of Lyman-alpha Emitters

We consider a forming galaxy undergoing multitudinous SN explosions as a possible model of Lyman alpha emitters.
To verify this model, high-resolution hydrodynamic simulations are performed using 1024^3 grid points, where SN remnants are resolved with sufficient accuracy.

- **Three-dimensional hydrodynamics : Shock captured TVD(AUSM-DV)**
- **Gravity of dark matter halos**
- **Radiative cooling (including H_2 molecule and metals)**
- **Star formation**
- **Supernova feedback (thermal energy and metals)**
- **Stellar emission: population synthesis model by Fioc 1997 (PÉGASE)**
- **Gas emission: Optically thin and collisional ionization equilibrium**
  Sutherland & Dopita 1993 (MAPPING III)

Parameters

Total mass : 10^8-10^{12} $M_\odot$

(Ω_M=0.3, Ω_Λ=0.7, h=0.7, z=7.8, Ω_b=0.024 h^{-2})

Sub-galactic system: *N*-body dynamics

We model a proto-galaxy as an assemblage of numerous sub-galactic condensations building up the total mass of a galaxy.

Example) 10^{11} $M_\odot$: Sub-galactic unit has a mass of 5×10^9 $M_\odot$ and virialize at z=7.8.

Star formation : Shmidt-type law

$\tau_{cool} < \tau_{ff} < \tau_{cros}$

$d\rho_* / dt = C_* \rho_g / \tau_{ff}$

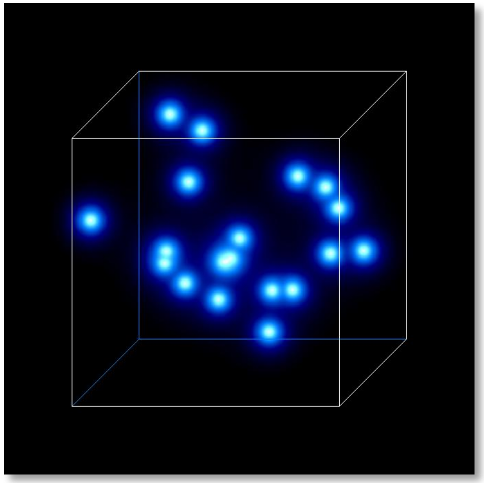
Local star formation efficiency: C_*=0.1

Salpeter's IMF

Supernova feedback:

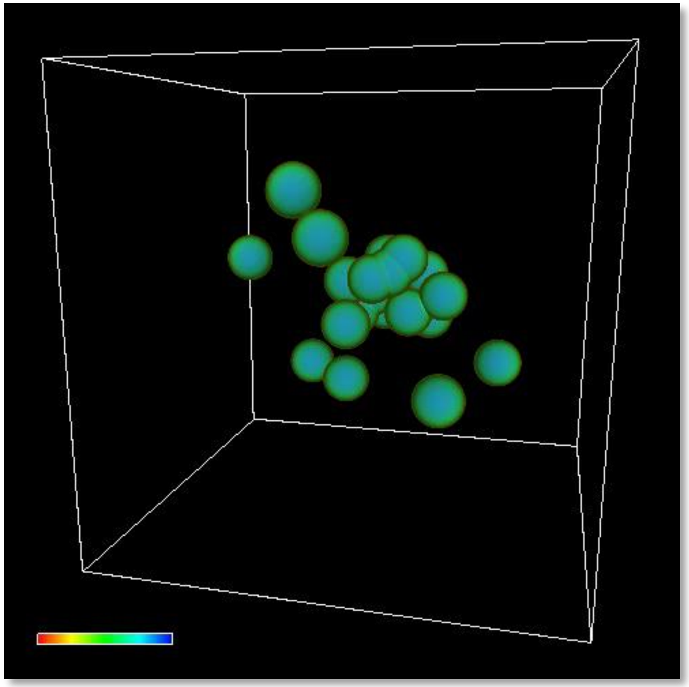
$E_{SN} = 10^{51}$ erg / SN (thermal energy)

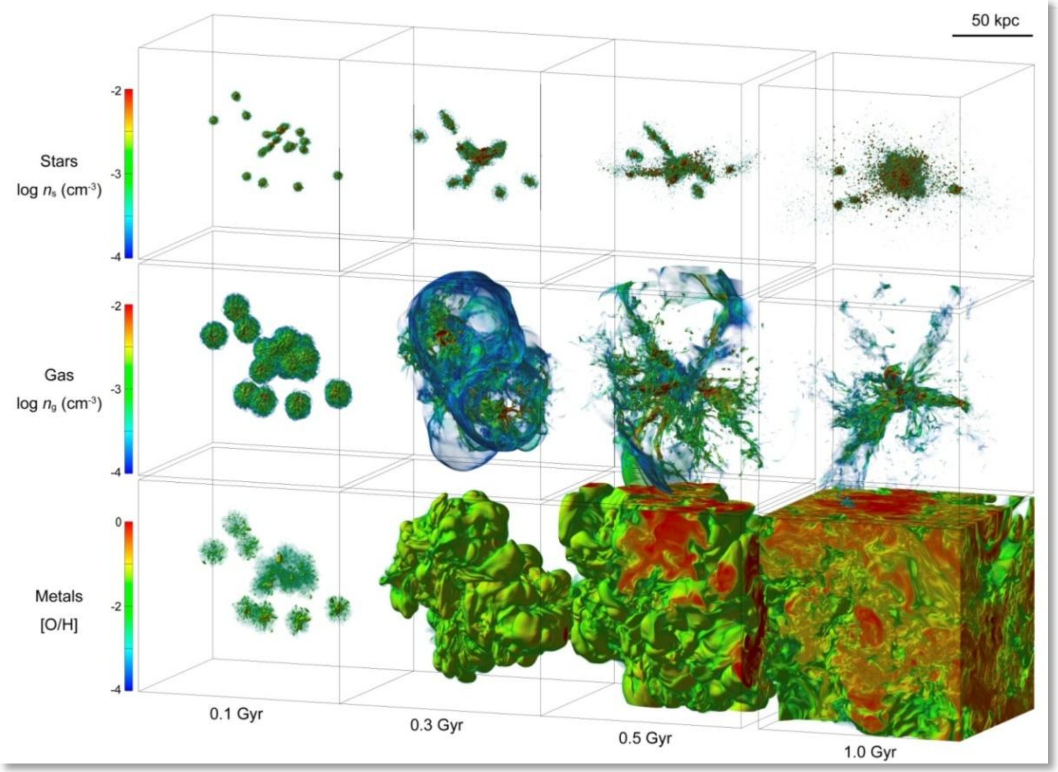
Oxygen : 2.4 $M_\odot$ / SN



Simulation result

Mori & Umemura, Nature, 440, 644 (2006)

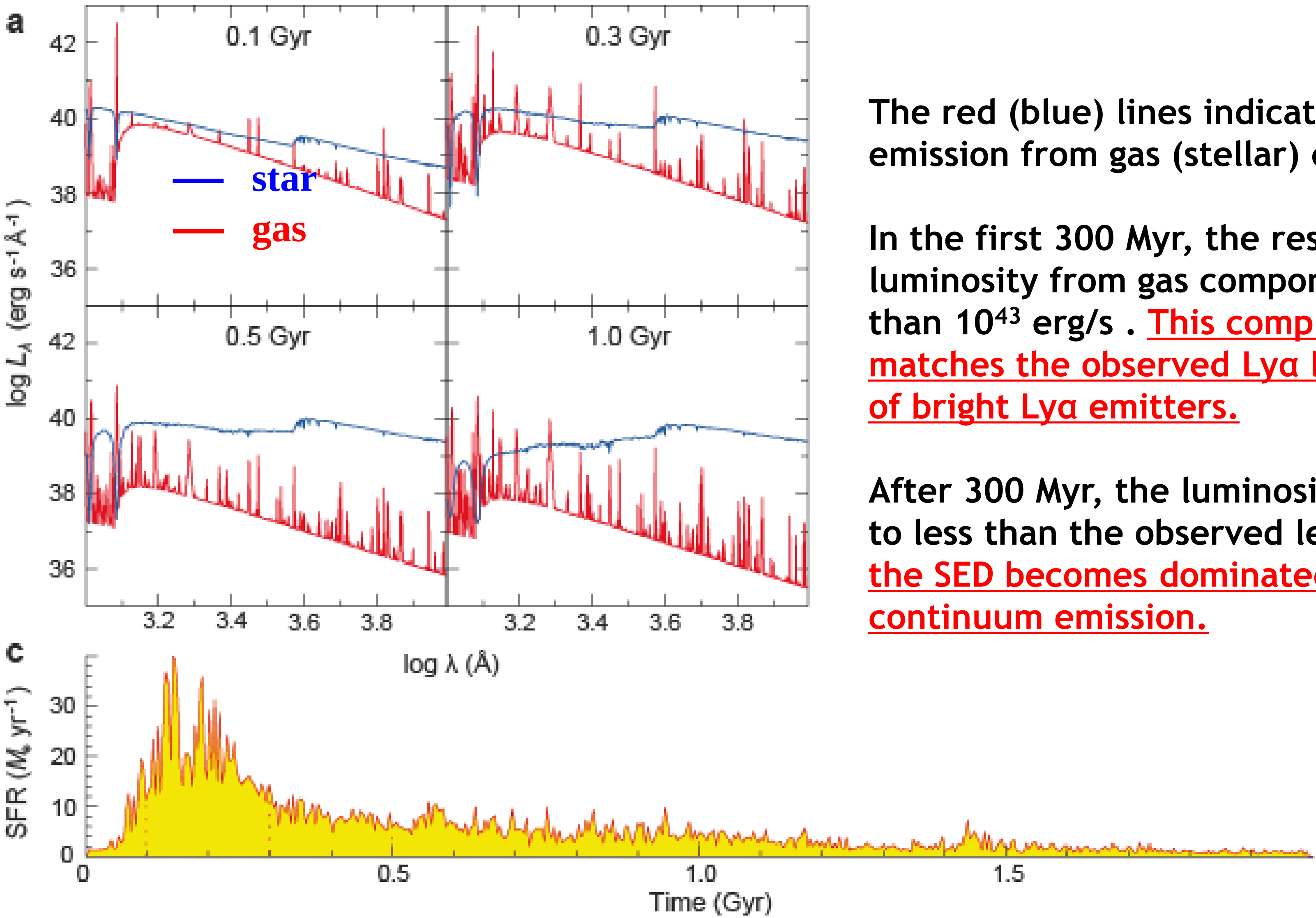




These bubbly structures (middle panels in right fig.) suggest that supernova events could be closely related to observed LAEs. So we think these complexes of various super-bubbles driven by multiple supernovae are an attractive explanation for extended LAEs.

SED : Gas and Stars

Mori & Umemura, Nature, 440, 644 (2006)



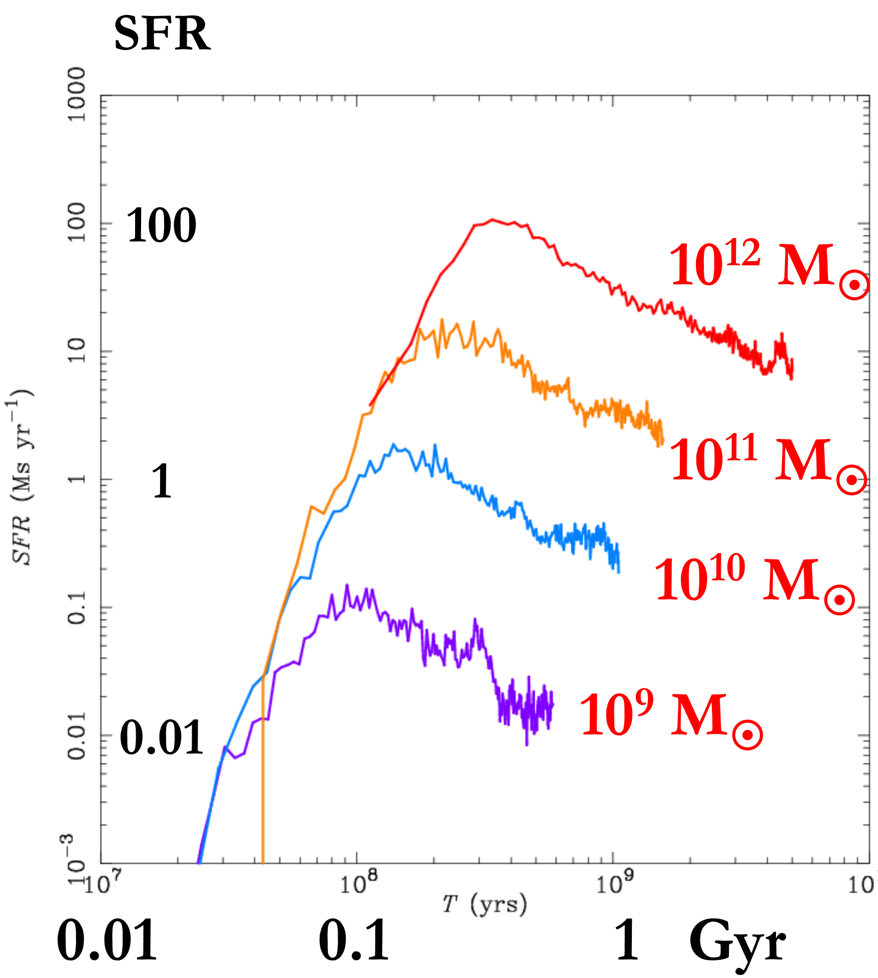
The red (blue) lines indicate the emission from gas (stellar) component.

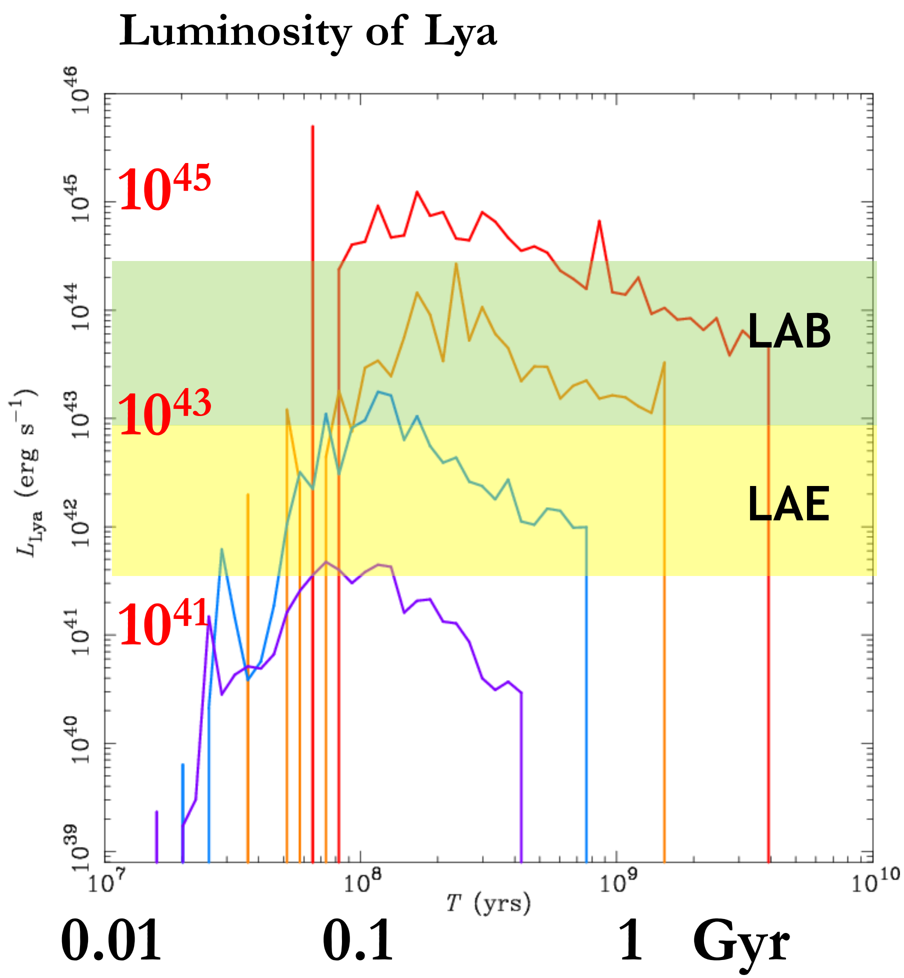
In the first 300 Myr, the resultant Lyα luminosity from gas component is more than 10^{43} erg/s . This completely matches the observed Lyα luminosities of bright Lyα emitters.

After 300 Myr, the luminosity declines to less than the observed level. Then, the SED becomes dominated by stellar continuum emission.

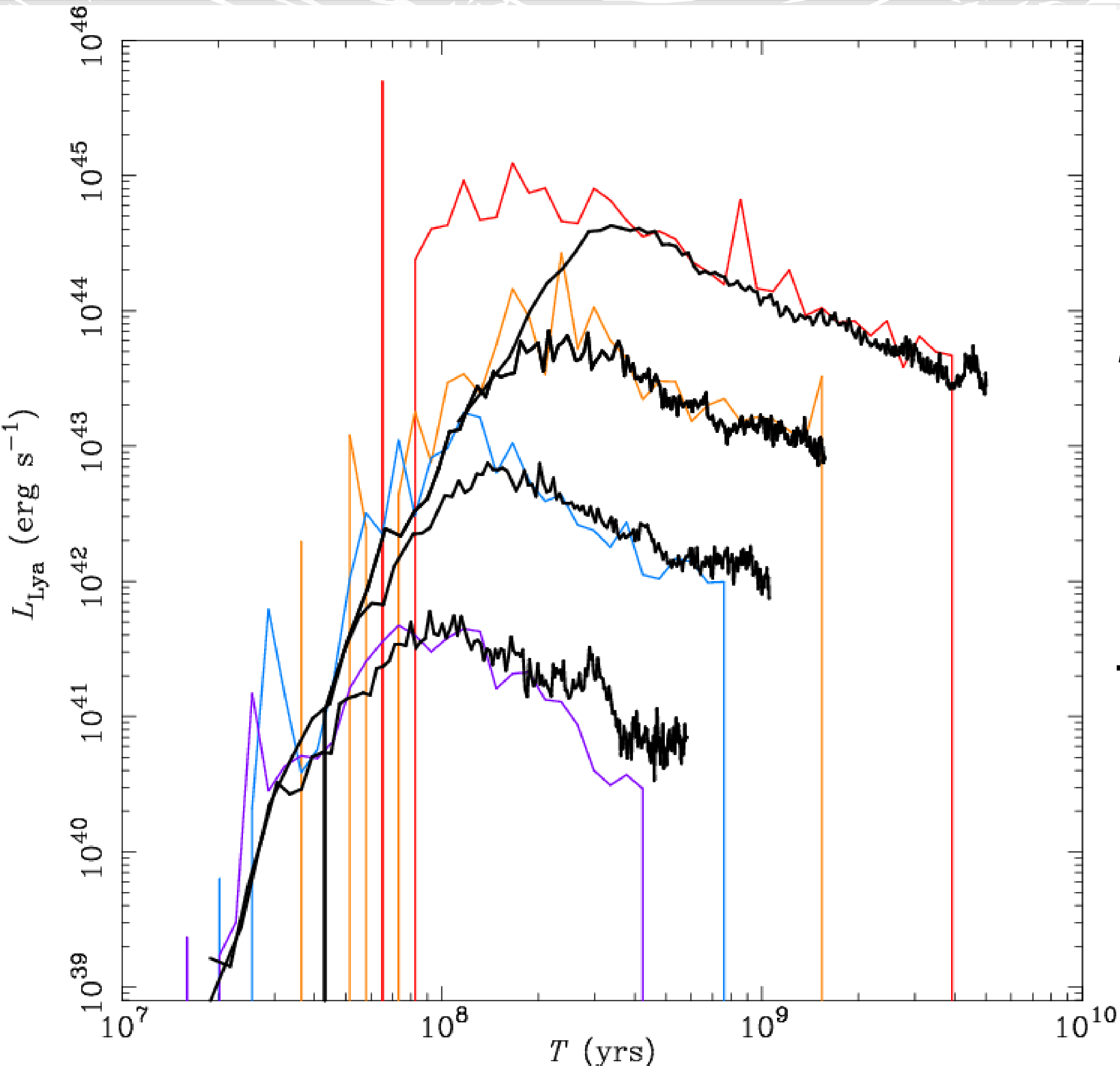
Star formation rate and Lyman alpha luminosity

Mori, Yajima & Umemura, in prep.





Scaling relation between SFR and Lya luminosity
Mori, Yajima & Umemura, in prep.



$L_{cooling} \approx 4\times10^{42}\ SFR$

cf. Kennicutt law:

$L_{nebula} = 10^{42}$ (erg s^{-1}) SFR (M_s yr^{-1})

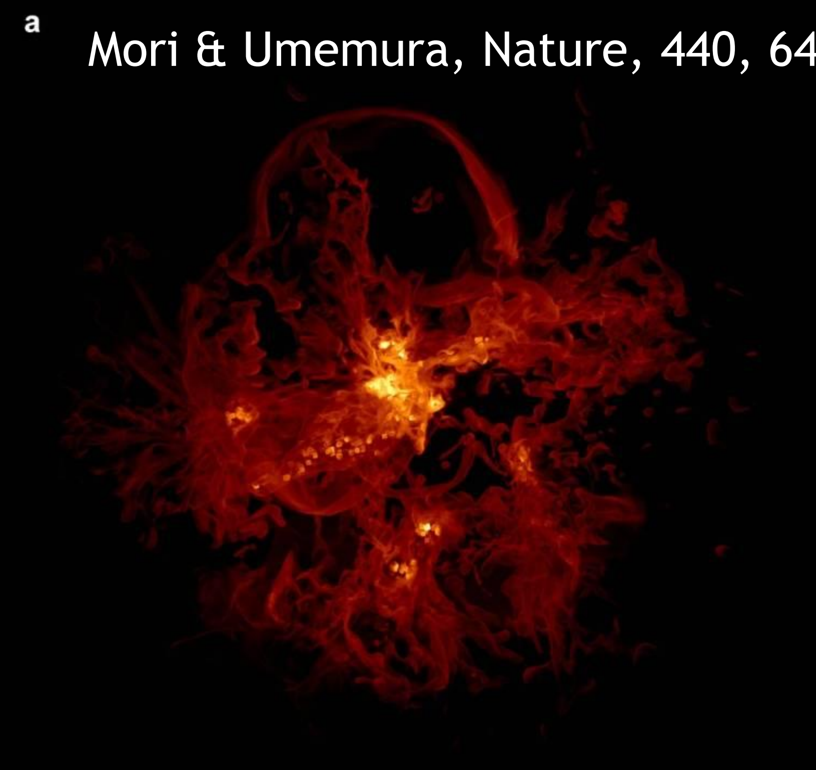
Total Lya luminosity:

$L_{total} = L_{nebula} + L_{cooling}$

$= 5 \times 10^{42}\ SFR$

Comparison of simulation and observation

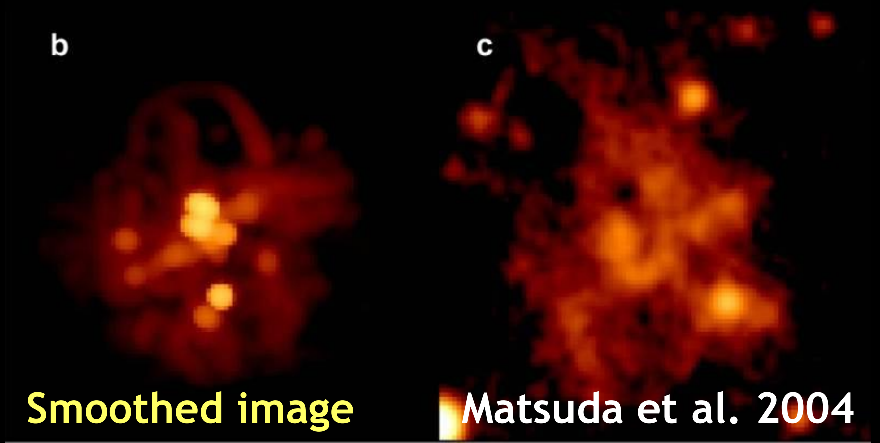
Mori & Umemura, Nature, 440, 644 (2006)



Upper: Projected distribution of Lyα emission derived by numerical results

Lower left: Simulation result smoothed with a Gaussian kernel with a FWHM of 1.0”

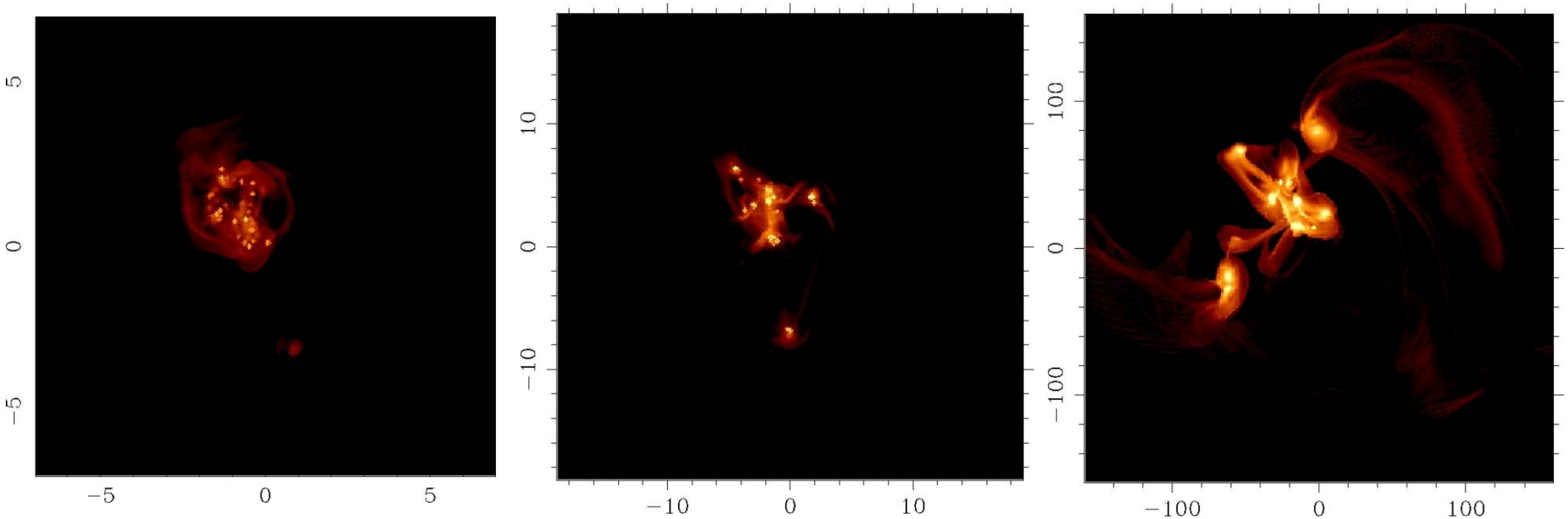
Lower right: Lyα image of the LABs observed by Matsuda et al. (2004)



Spatial distribution of Lyα emission

Mori, Yajima & Umemura, in prep.

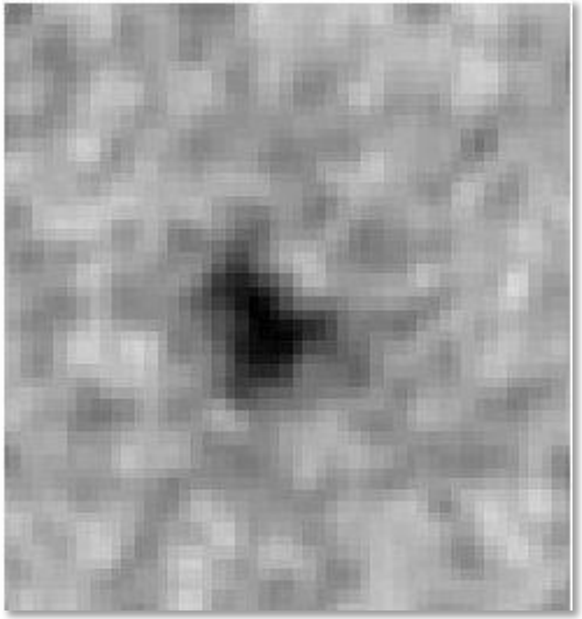
$M=10^9 M_\odot$ z=8.1 — 1 arcsec=4.8 kpc
$M=10^{10} M_\odot$ z=6.2 — 5.6 kpc
$M=10^{12} M_\odot$ z=3.0 — 7.7 kpc



Theoretical Lyα emission comes mainly from high density regions.
The filamentary structures are produced by the galaxy merger and multiple SN explosions. At the lower redshift, these galaxies with the complicated structures are observed as Lyman alpha emitters. But the higher redshift, most of structures become unclear due to the limited resolution.

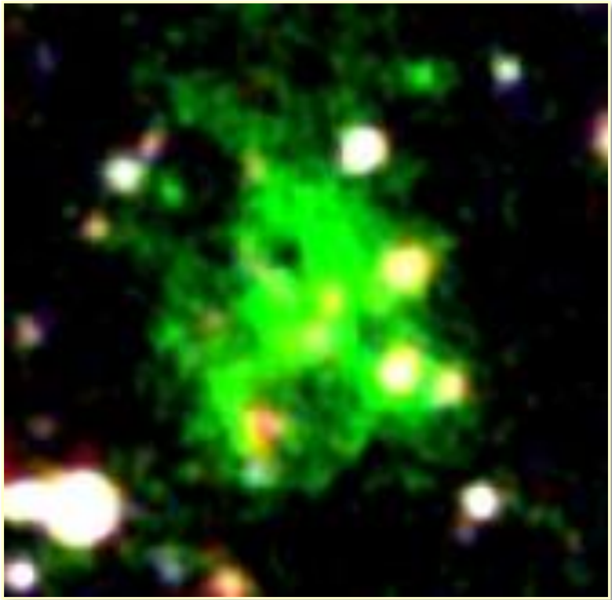
Compact LAEs and Extended LAEs

Compact LAE



Private communication with Hayashino, Mastuda, Yamada, Nakamura et al.

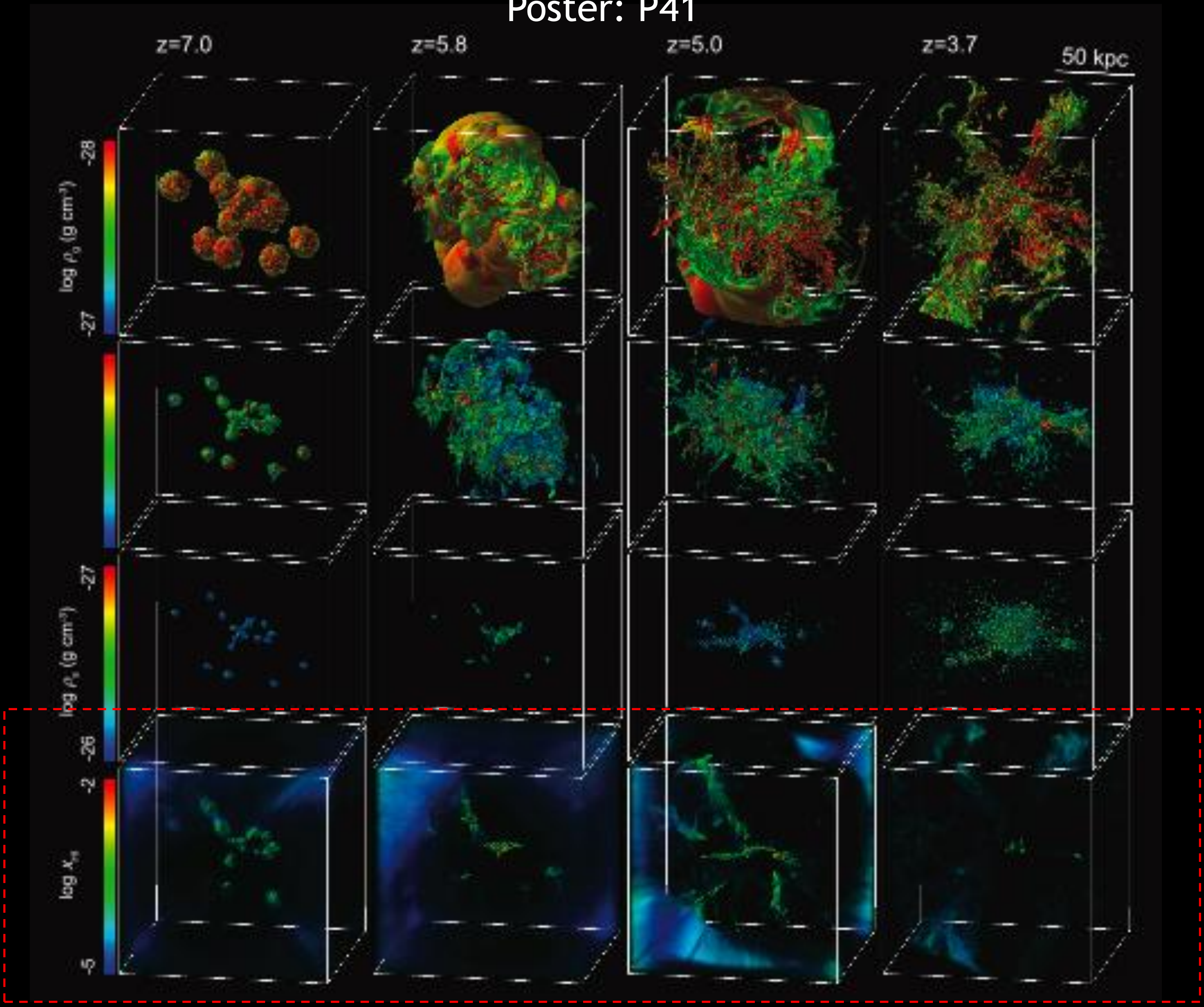
Extended LAE



Matsuda et al. 2004

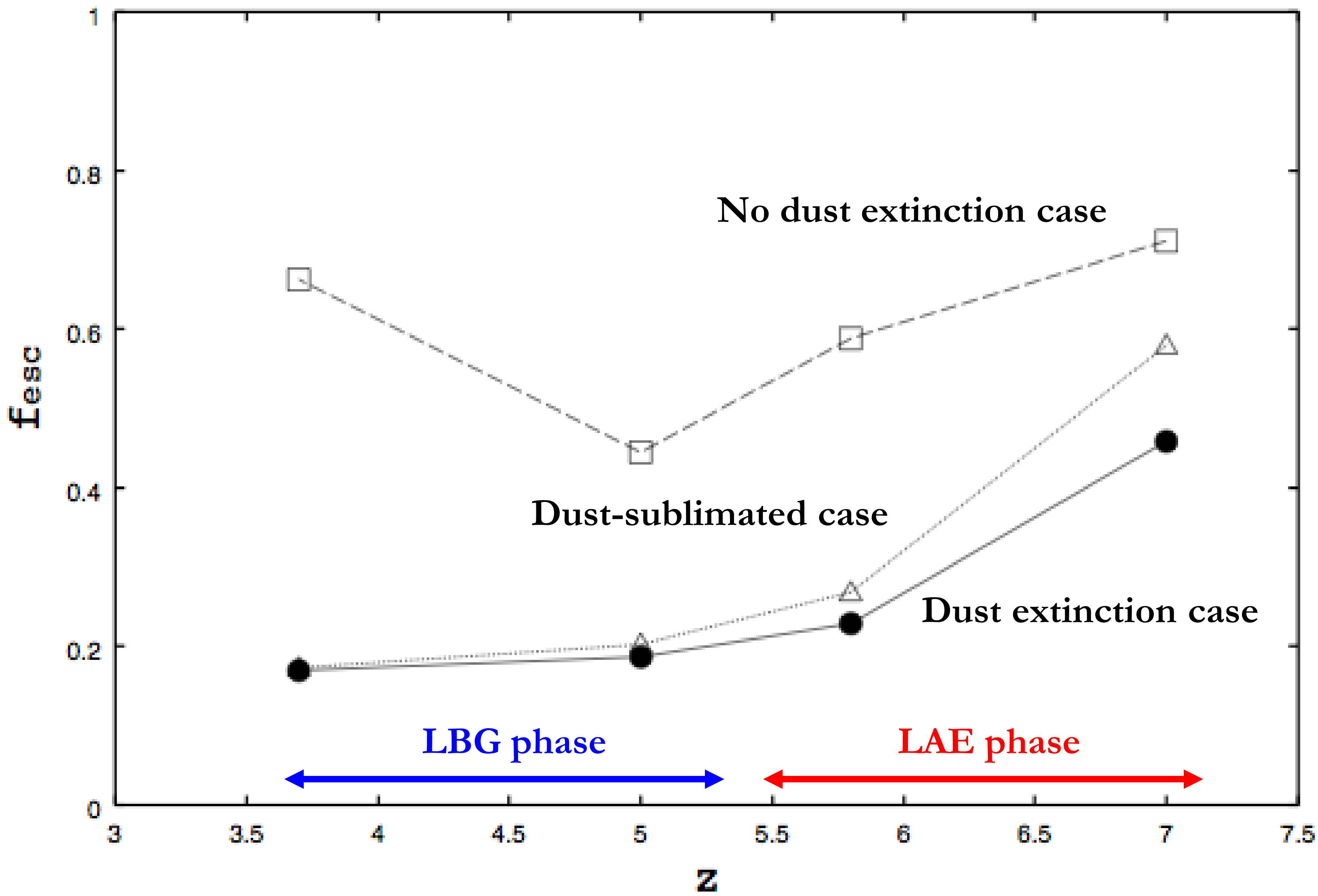
Ionization structure

Yajima et al. accepted to MN (arXiv:0906.1658)
Poster: P41



Escape fraction of ionizing photons

Yajima et al. accepted to MN (arXiv:0906.1658)



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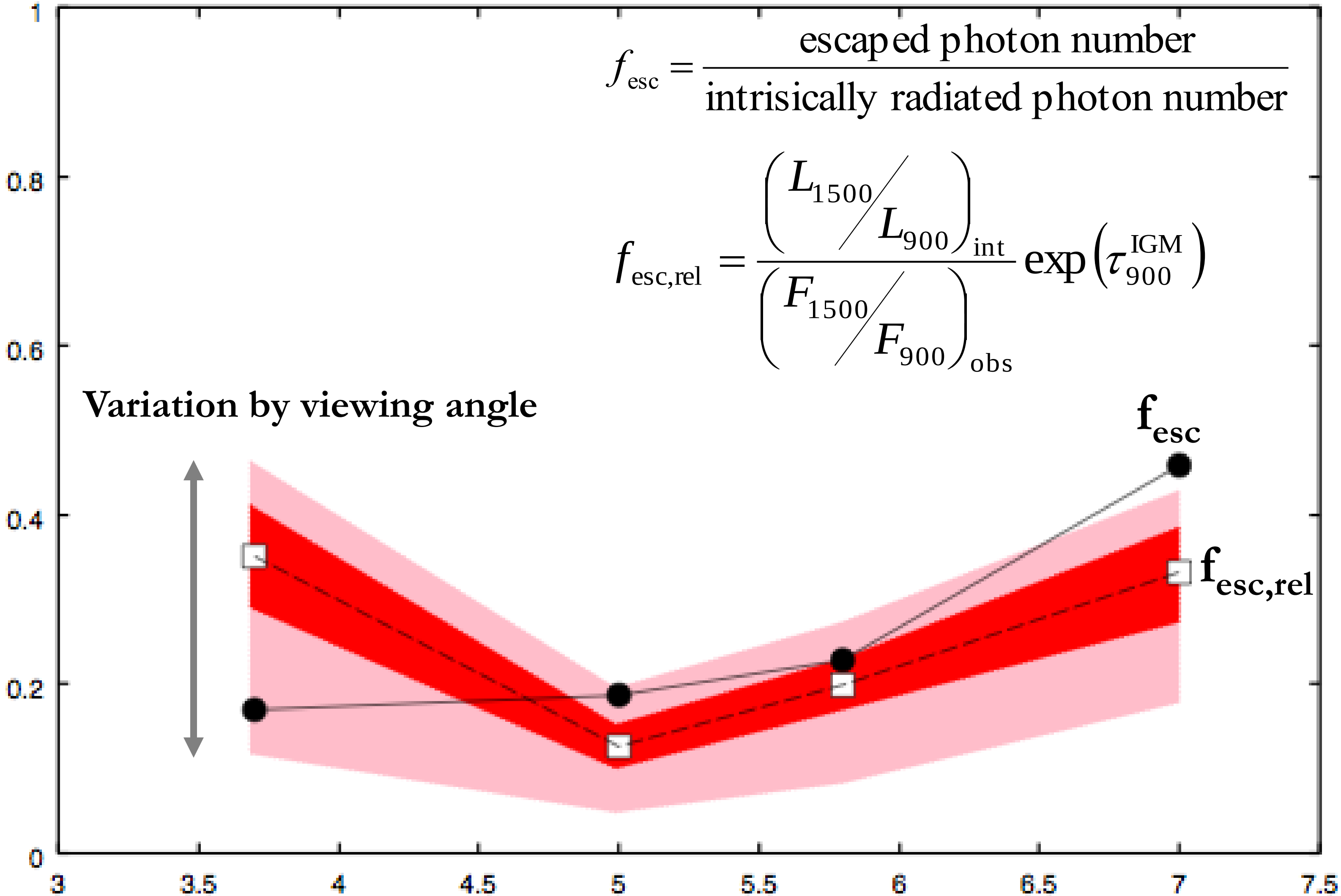
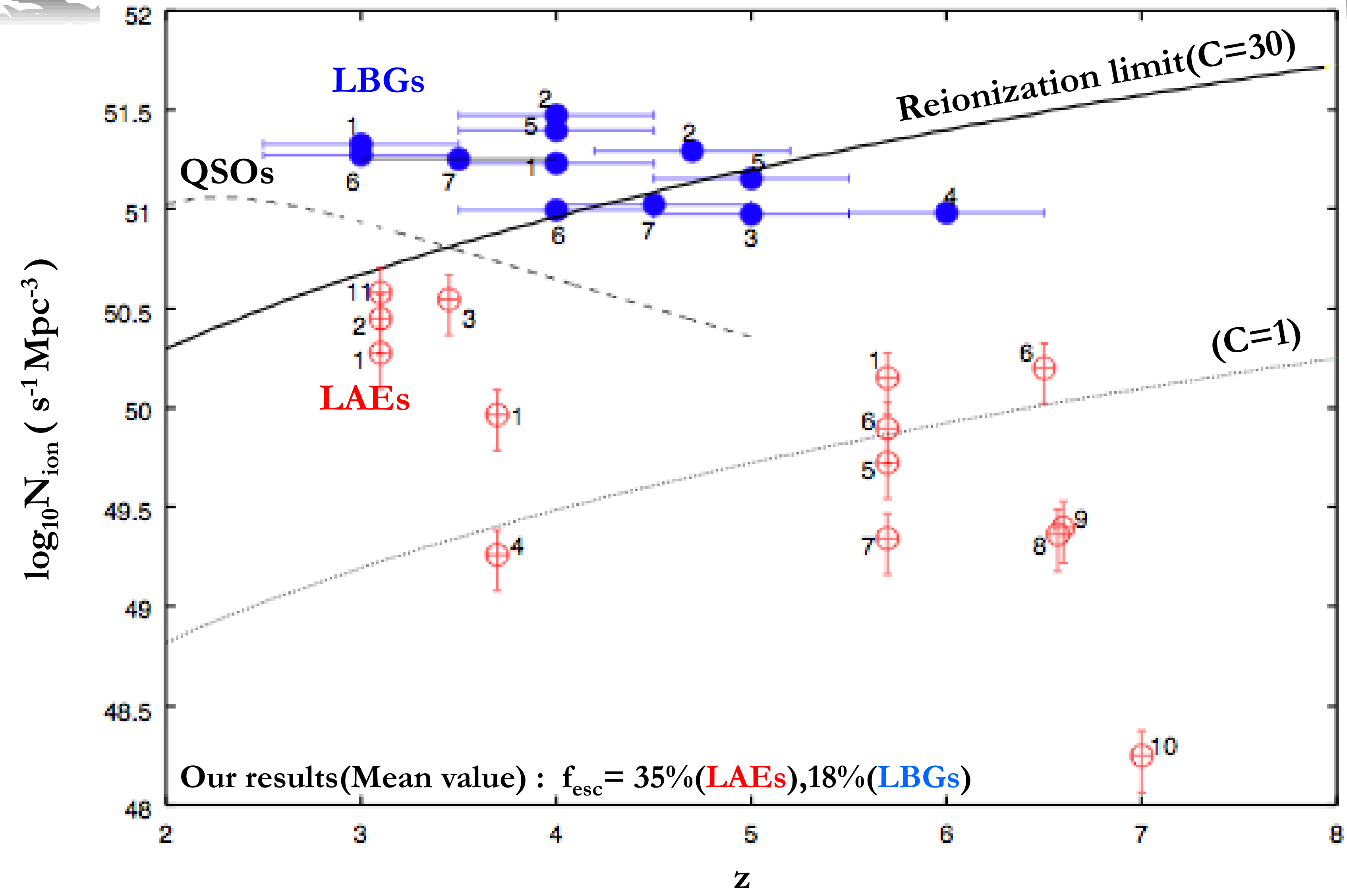


$$f_{\rm esc} = \frac{\text{escaped photon number}}{\text{intrisically radiated photon number}}$$

$$f_{\rm esc,rel} = \frac{\left(L_{1500} / L_{900} \right)_{\rm int}}{\left(F_{1500} / F_{900} \right)_{\rm obs}} \exp\left(\tau_{900}^{\rm IGM}\right)$$

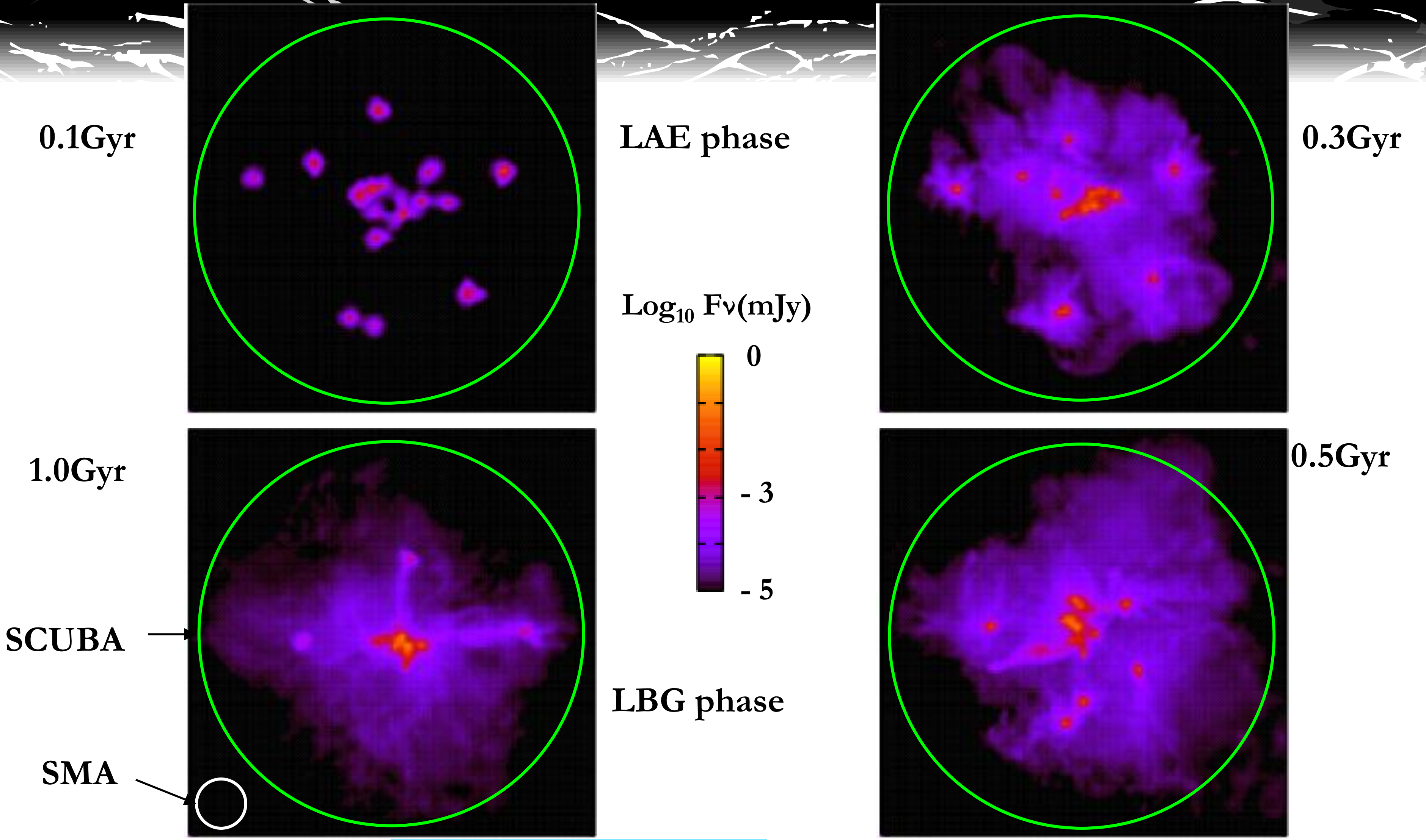
Ionizing photons from LAEs and LBGs

Yajima et al. accepted to MN (arXiv:0906.1658)



850μm flux image

Yajima et al, in prep.



Cell size ~ 0.13”

ALMA → 0.01”

SMA → 2”

SCUBA → 15”

Summary

- We have suggested that Lyα emitters can be identified with primordial galaxies catched in a supernova-dominated phase.
- The bubbly structures produced by multiple SN explosions are quite similar to the observed features in Lyα surface brightness of extended Lyα emitters.
- The resultant Lyα luminosity can account for the observed luminosity of Lyα emitters.
- After a few 100 Myr the simulated galaxy is dominated by stellar continuum radiation and looks like the Lyman break galaxies. The results of our simulation indicates the possible link between Lyα emitters and Lyman break galaxies.
- LAEs and LBGs have a large escape fraction (17% ~ 47%). (theoretical previous works → ~3%). The escape fraction can largely vary by the inhomogeneous spatial distribution of dust.
- The spatial distribution of IR flux shows a diffuse structure with filamentary structures.