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Formation of Lyα emitting galaxies in overdense regions at the epoch of reionization

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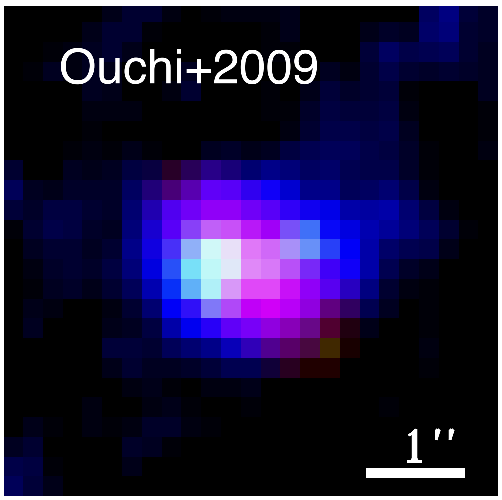
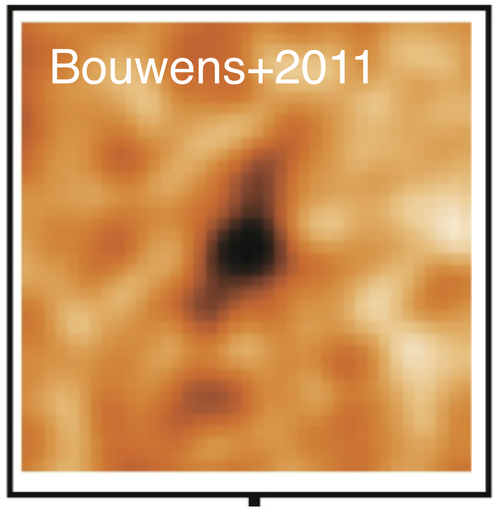
Various populations in high-z galaxies

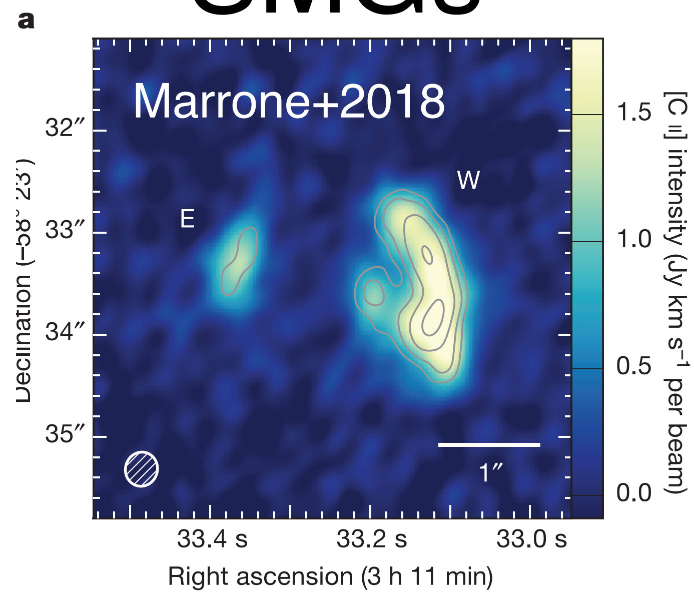
LAEs/LABs



LBGs



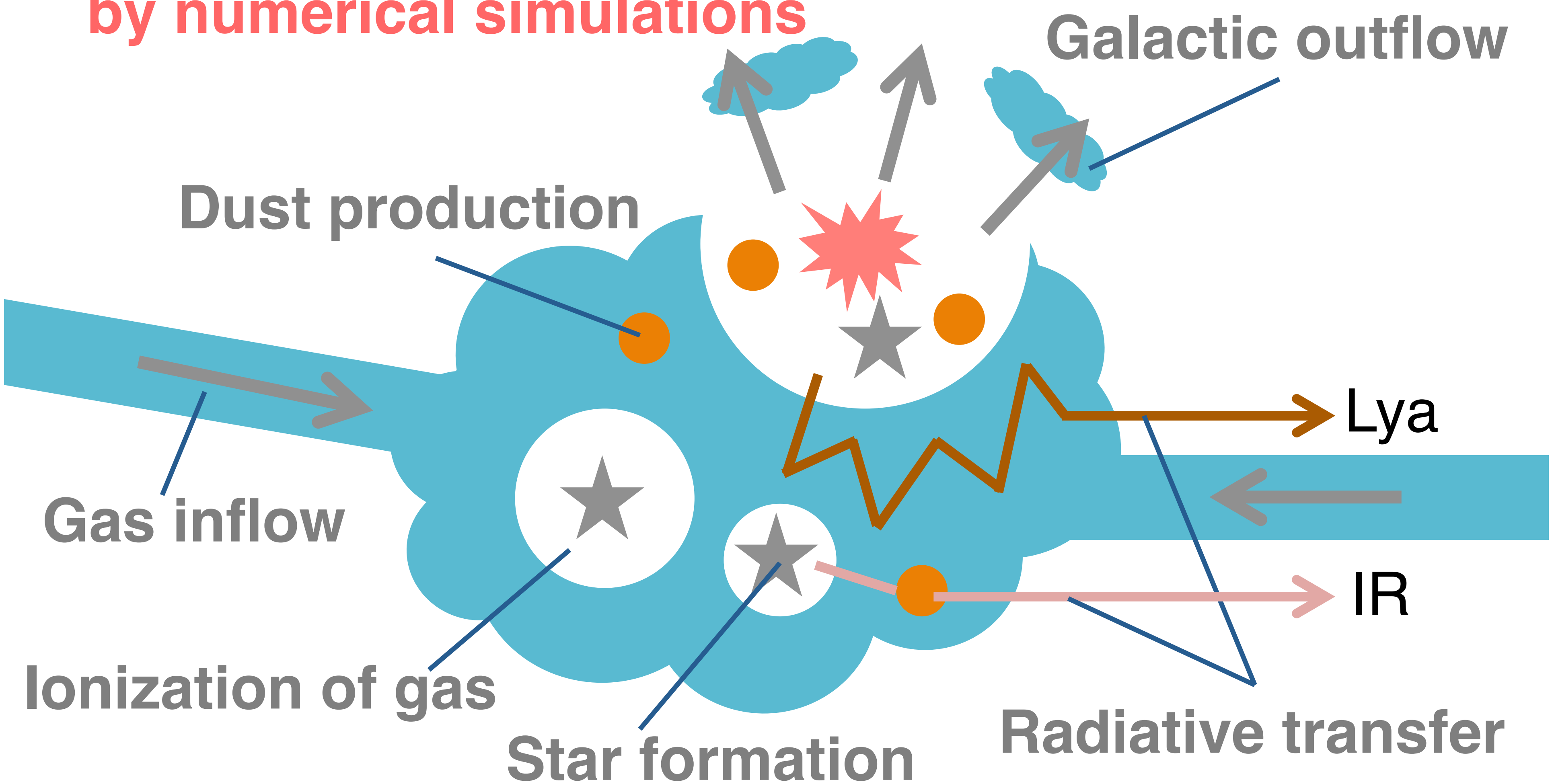
SMGs



What caused the diversity?
How did the radiation property change with galaxy evolution?

Galaxy evolution and radiation properties

We directly calculate these processes by numerical simulations



Methodology and Basic physics

Cosmological hydrodynamics simulations

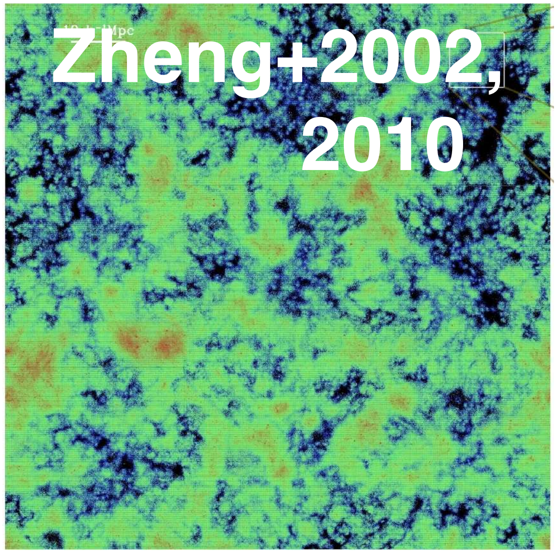
+

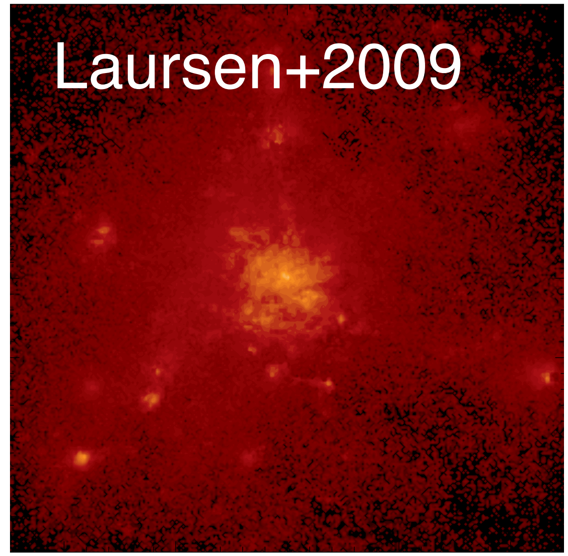
Radiation transfer calculations

Previous works

(Cosmological hydro. + Lya radiative transfer)

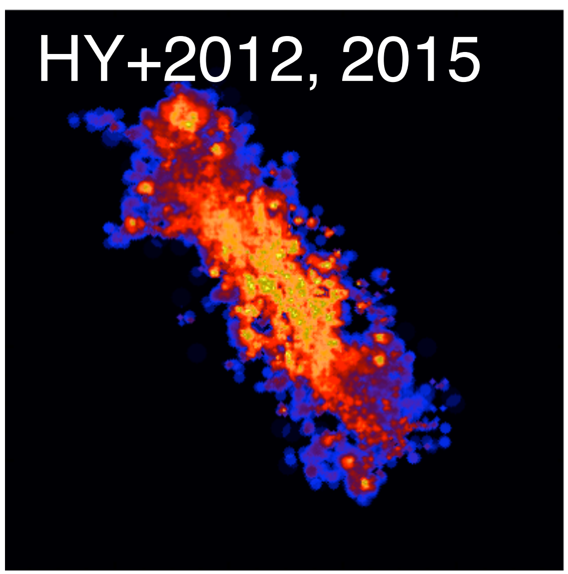
Pioneering works

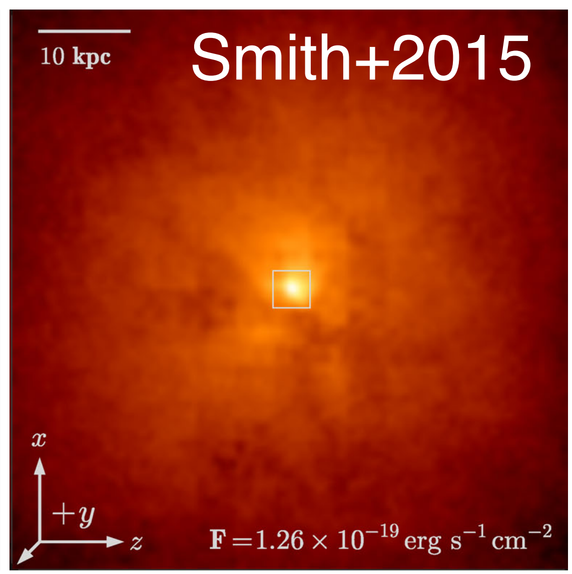




ISM with Dust

Dust, Multi-band, Milky Way-progenitors



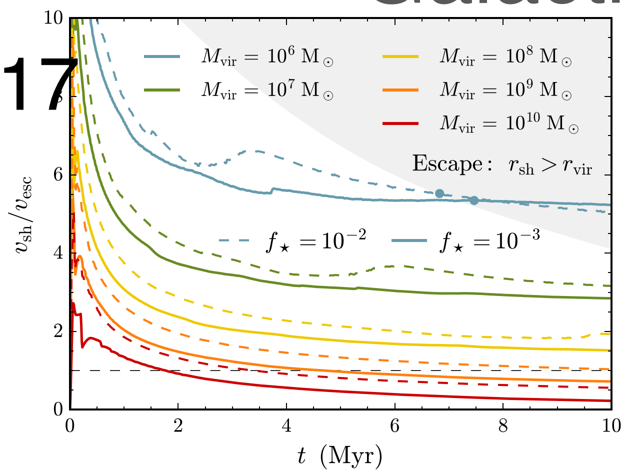


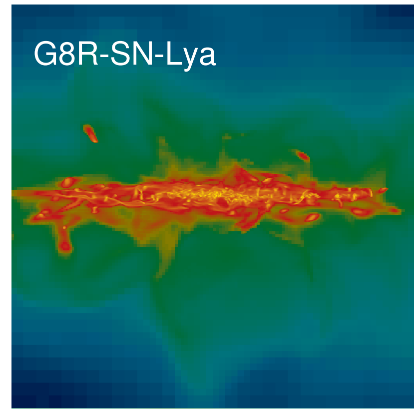
First gals. High-res.

Lya radiation feedback

Galactic outflow

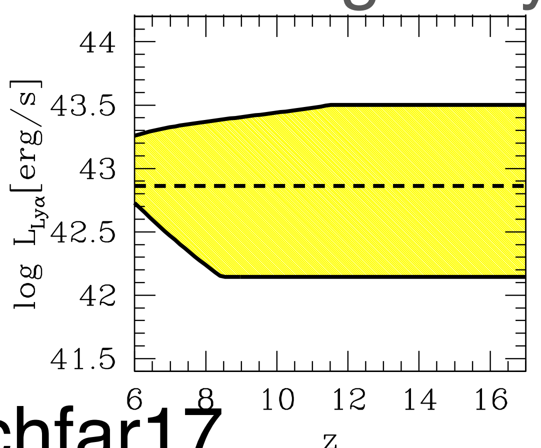
Smith+17





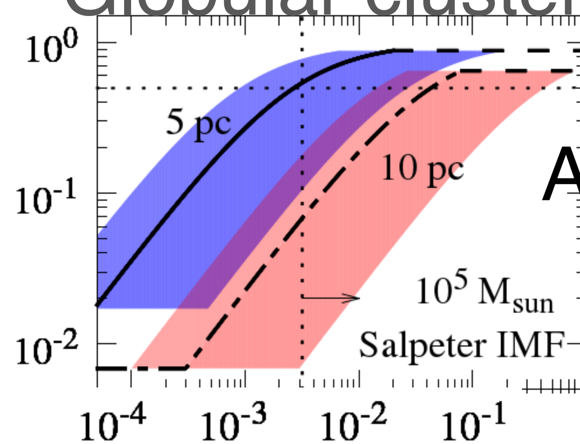
Kimm+18

POPIII galaxy



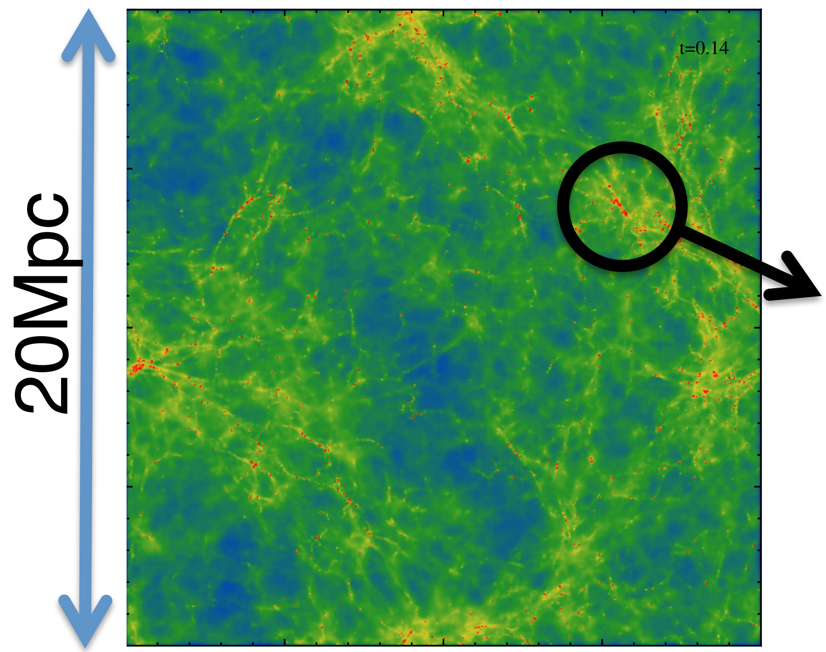
HY&Khochfar17

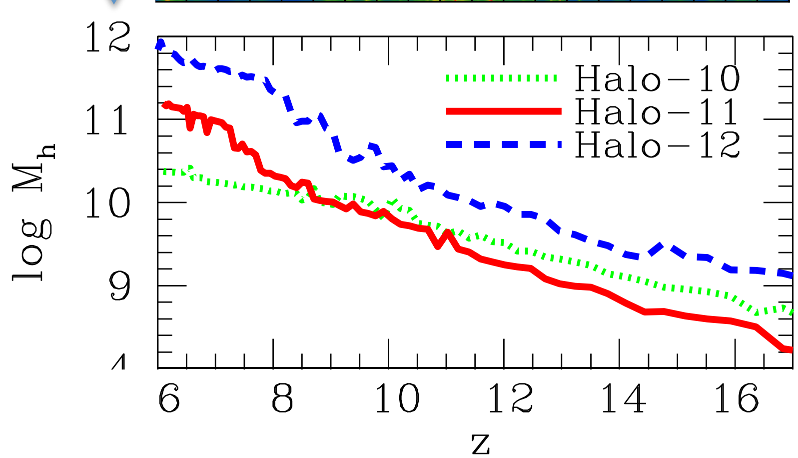
Globular clusters



Abe&HY18

Model&Setup





Cosmological zoom-in simulations with Gadget-3

a) <u>Halo-11 run</u>
2×10^{11} M_{sun} at z=6

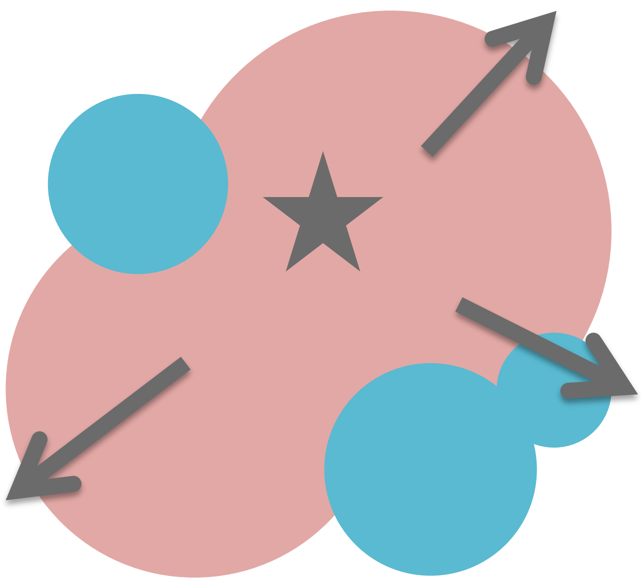
b) <u>Halo-12 run</u>
1×10^{12} M_{sun} at z=6

m_{gas}=1.2 $\times 10^4$ M_{sun} (1.8×10^5)
m_{DM}=6.6×10^4 M_{sun} (1.1×10^6)
Softening=200 pc(comoving)

Supernova feedback

(Dalla Vecchia & Schaye 2012)

Thermal energy is deposited
into neighbor SPH particles stochastically



T_{hot}=10^7.5 K
E=N_{SN} x 10^51 erg

Sound crossing time
v. s.
Cooling time

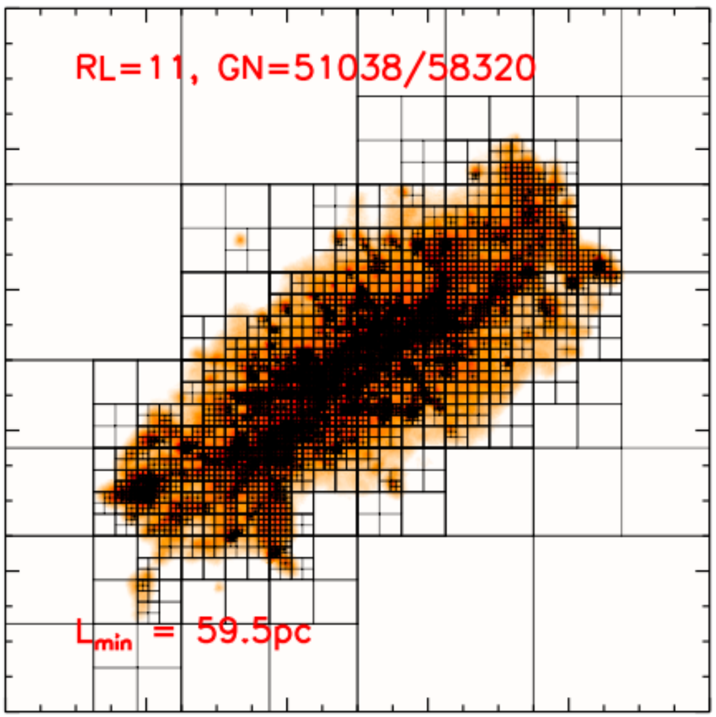
Critical density

$$n_{\rm H} \sim 100\ {\rm cm}^{-3} \left(\frac{T}{10^{7.5}\ {\rm K}}\right) \left(\frac{m_{\rm g}}{10^4\ {\rm M}_\odot}\right)^{-1/2}$$

3D Radiative Transfer code: ART^2

*All-wavelength Radiative Transfer with Adaptive Refinement Tree (ART^2)

(Li+2008; HY+ 2012, MNRAS, 424, 884)



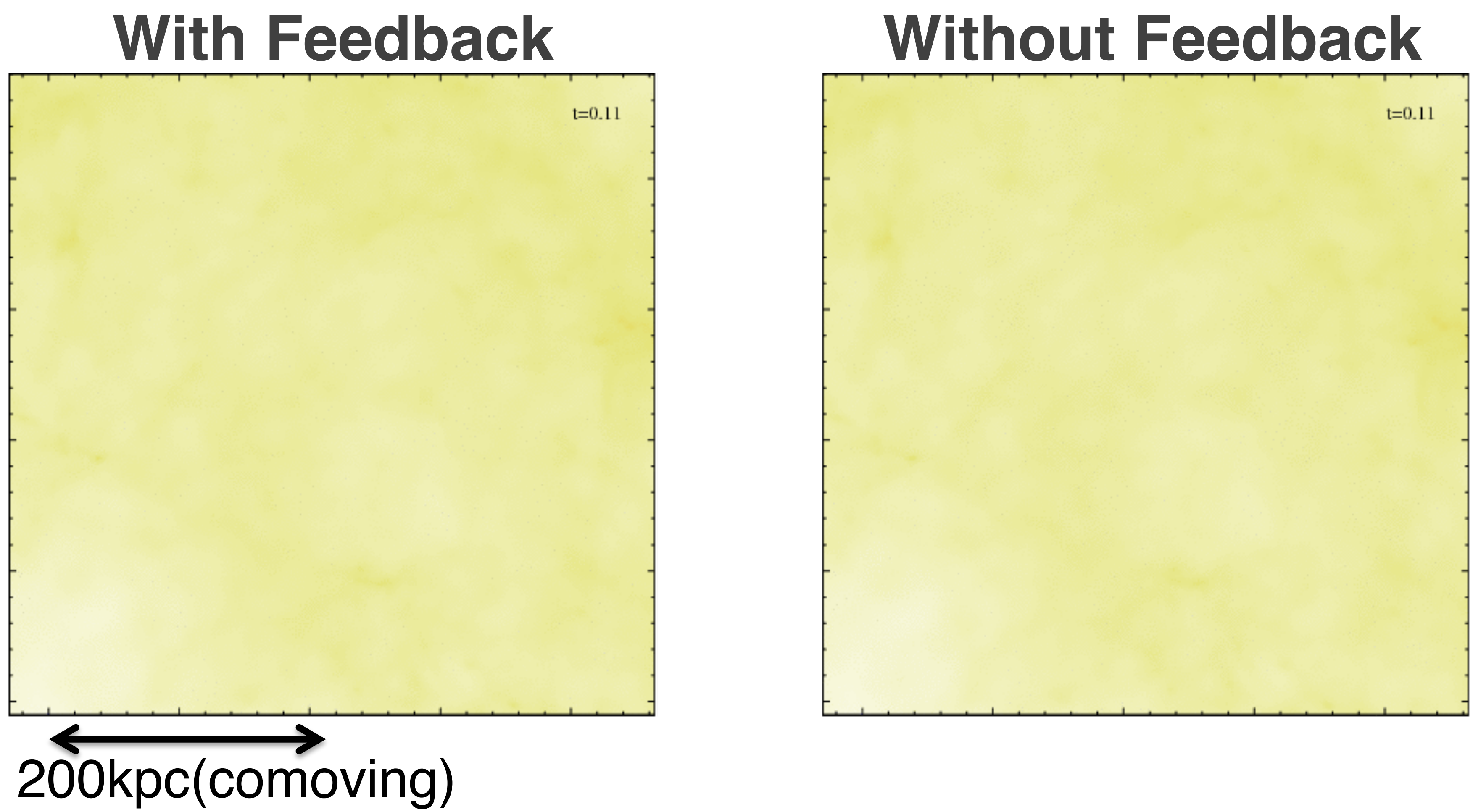
- Monte Carlo method
- Adaptive refinement grid structure
- Lyman-alpha line
- LyC and Ionization of hydrogen
- Continuum from X-ray to radio
- Dust absorption/emission
- Two-phase ISM model in a cell
- Parallelized

Results

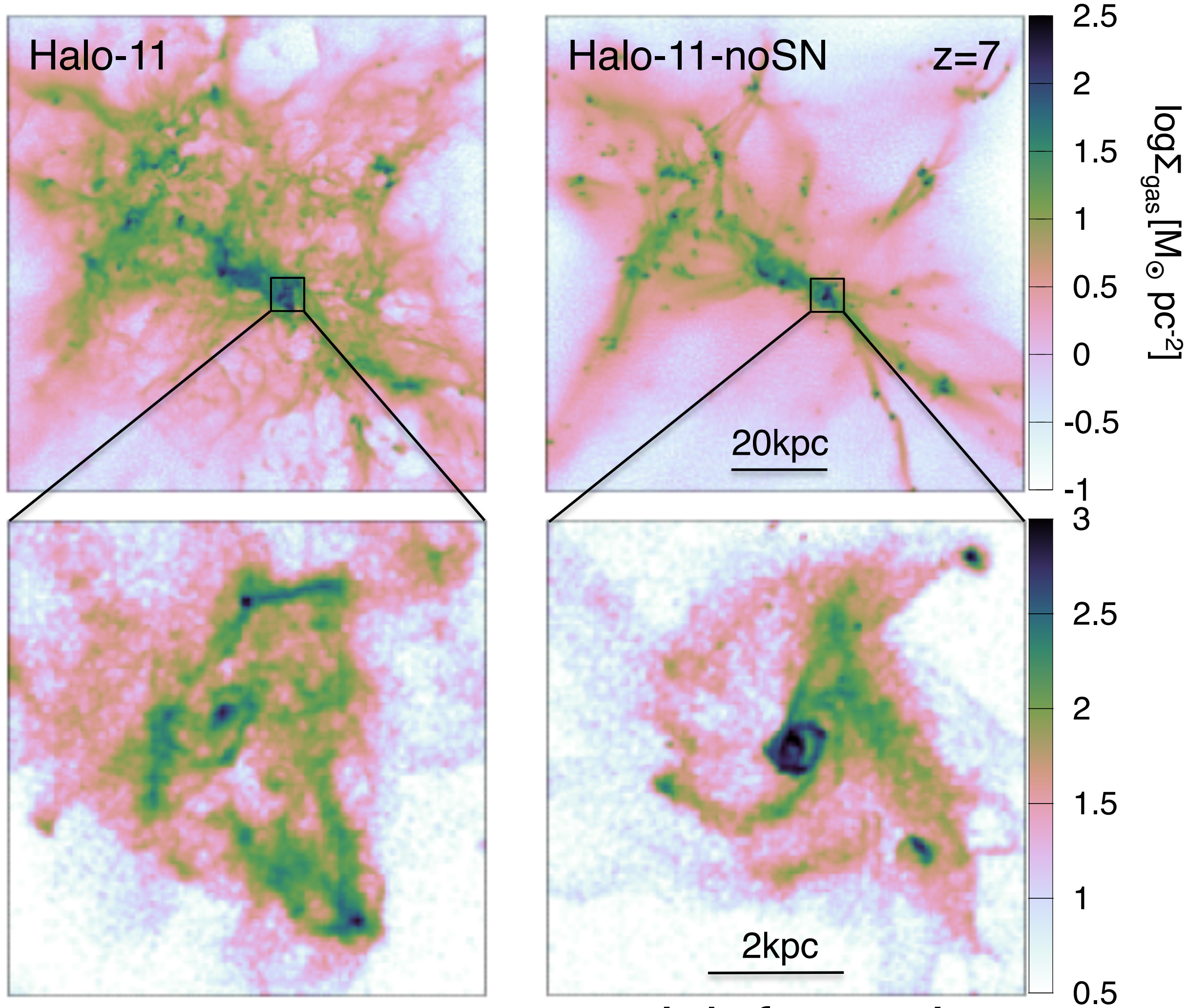
1) Star formation history (HY+2017, ApJ, 80, 30)
2) Lya properties
3) Case of Massive halos (HY, Arata+, in prep.)
4) UV/Sub-mm properties
5) Dust temperature (Arata, HY+, in prep.)

Gas structure in galaxies

(HY+2017, ApJ, 86, 30)



Formation of first galactic disks

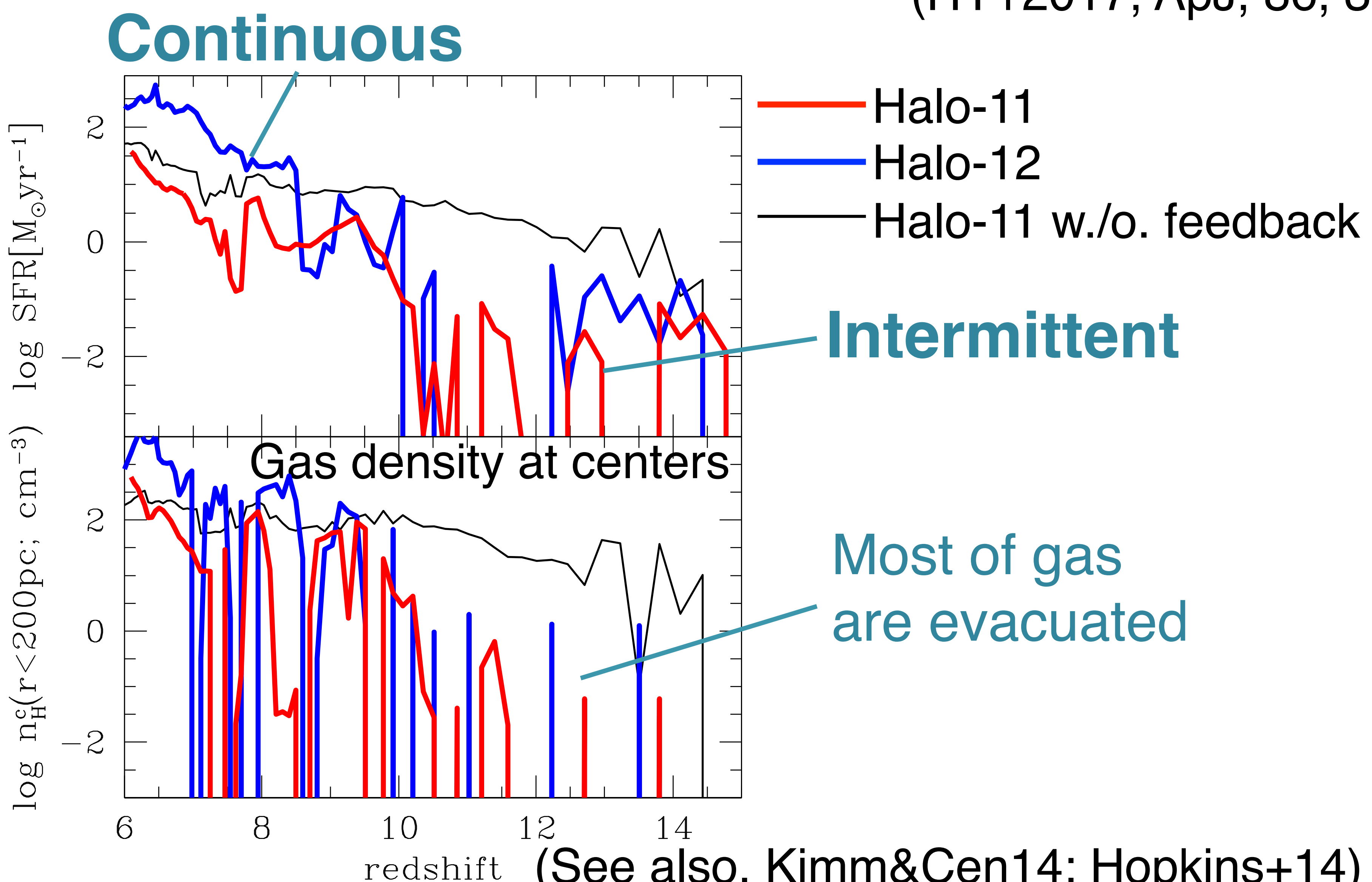


Destruction of disk

Disk formation

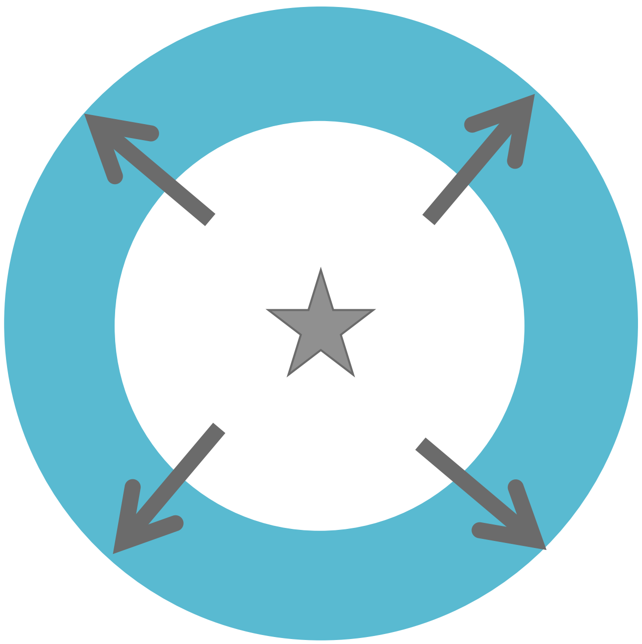
Star formation history

(HY+2017, ApJ, 86, 30)



(See also, Kimm&Cen14; Hopkins+14)

Consideration by the thin-shell approximation



$V_{\rm outflow} > V_{\rm esc}$?

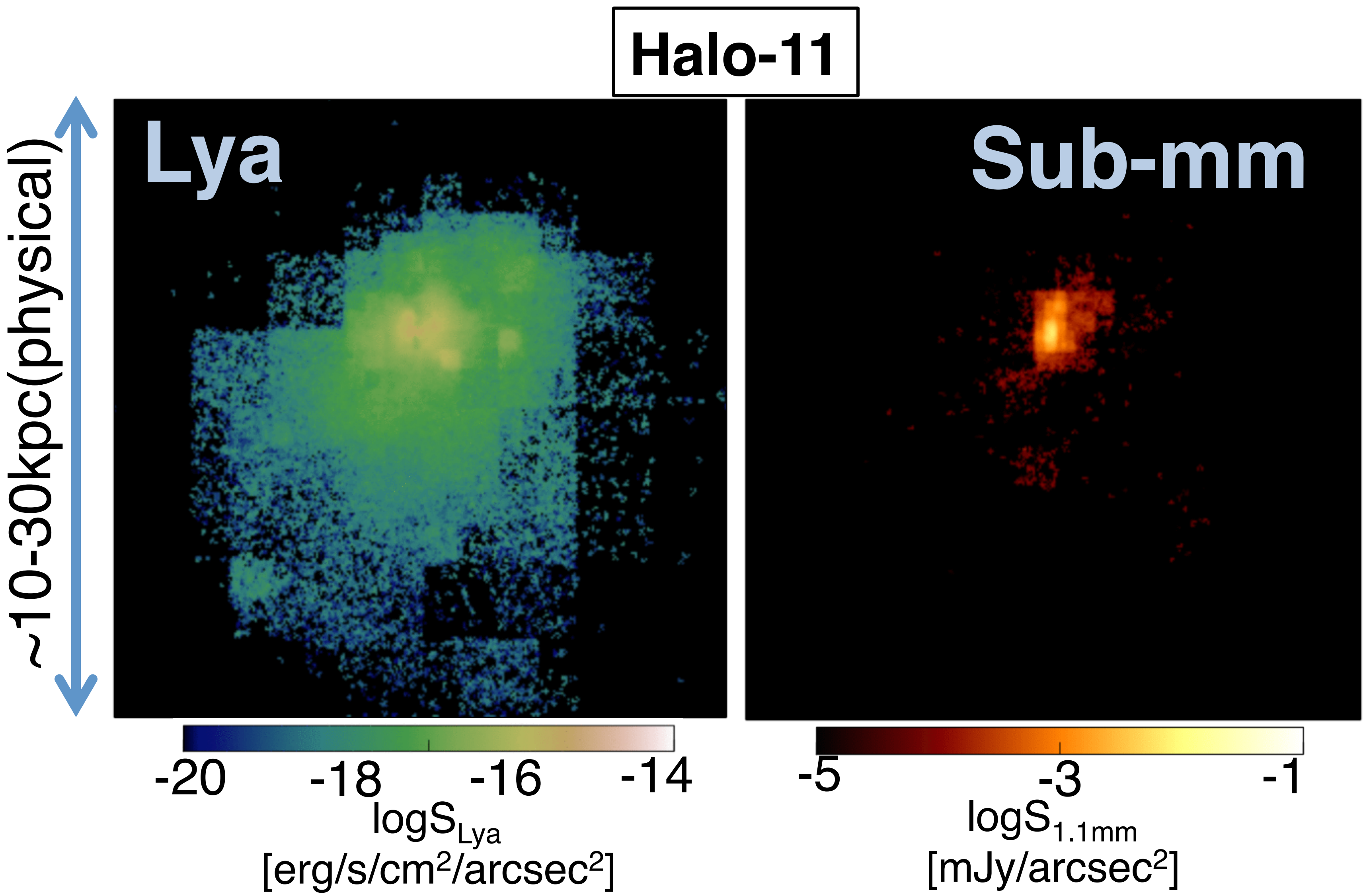
$$\eta_{\rm SN} E_{\rm SN} \sim \frac{1}{2} M_{\rm gas} V_{\rm outflow}^2$$

$$\frac{1}{2} M_{\rm gas} V_{\rm esc}^2 = \frac{G M_h M_{\rm gas}}{R_{\rm vir}}$$

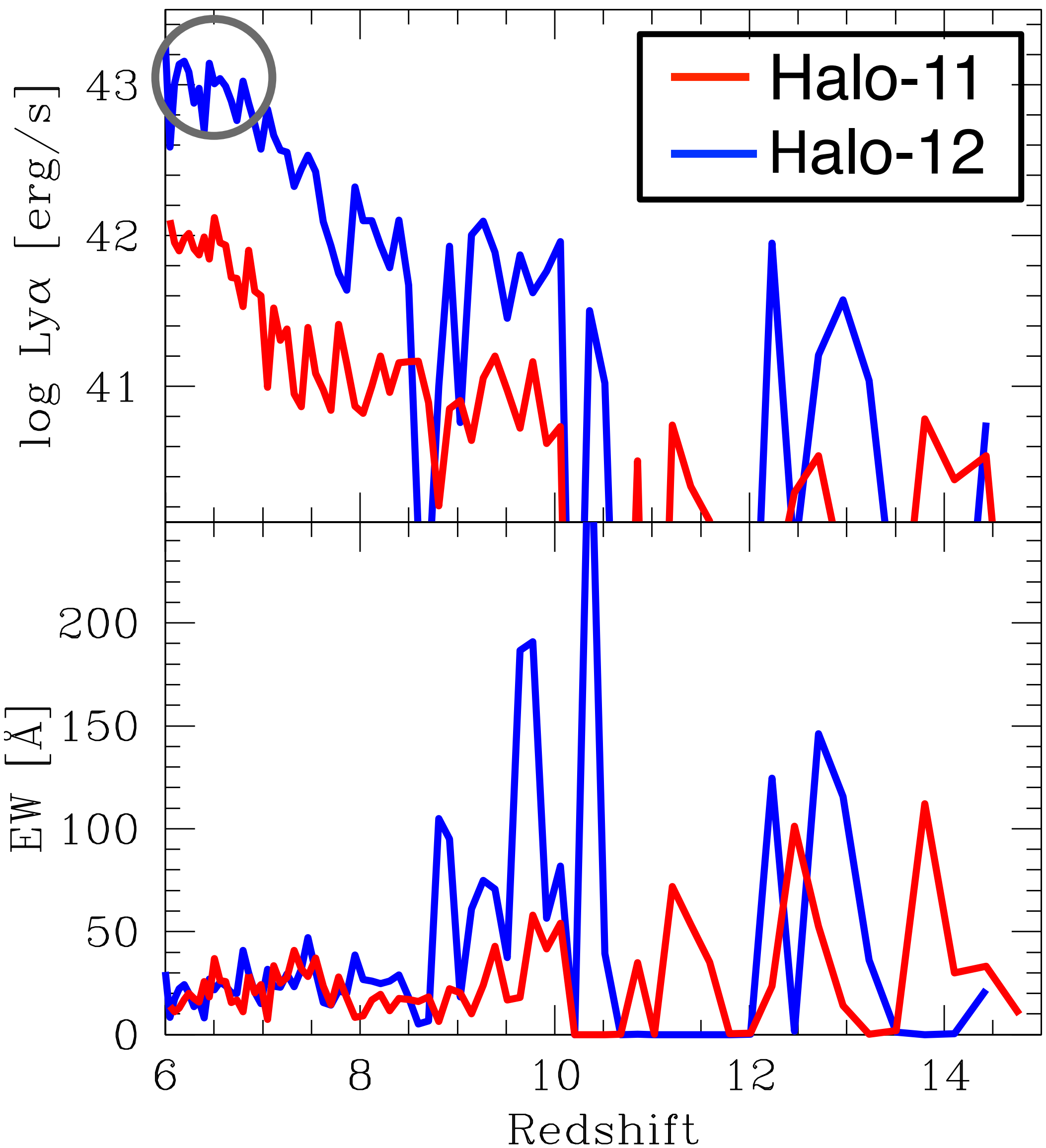
↓

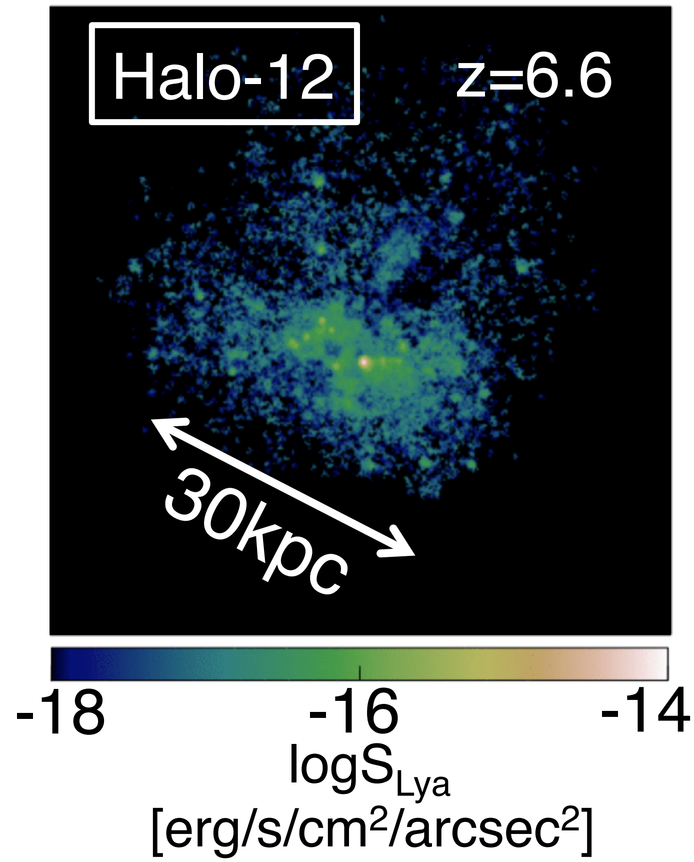
$$M_{\rm h,crit} = 0.3 \times 10^{10}\, M_\odot \left(\frac{\eta_{\rm SF}}{0.1}\right)^{3/2} \left(\frac{\eta_{\rm SN}}{0.5}\right)^{3/2} \left(\frac{1+z}{11}\right)^{-3/2}$$

Surface brightness(z=10➔6)

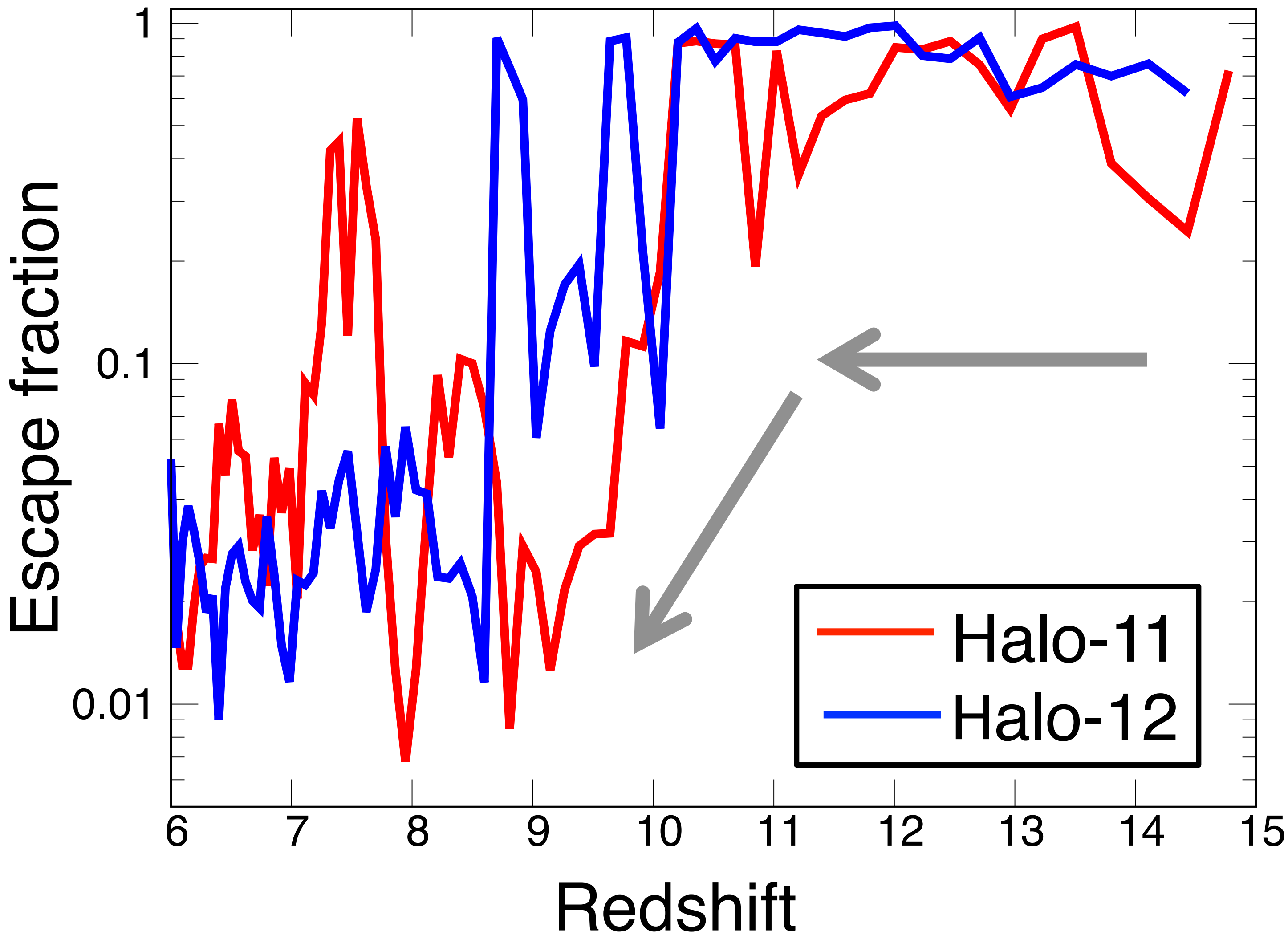


Lya luminosity

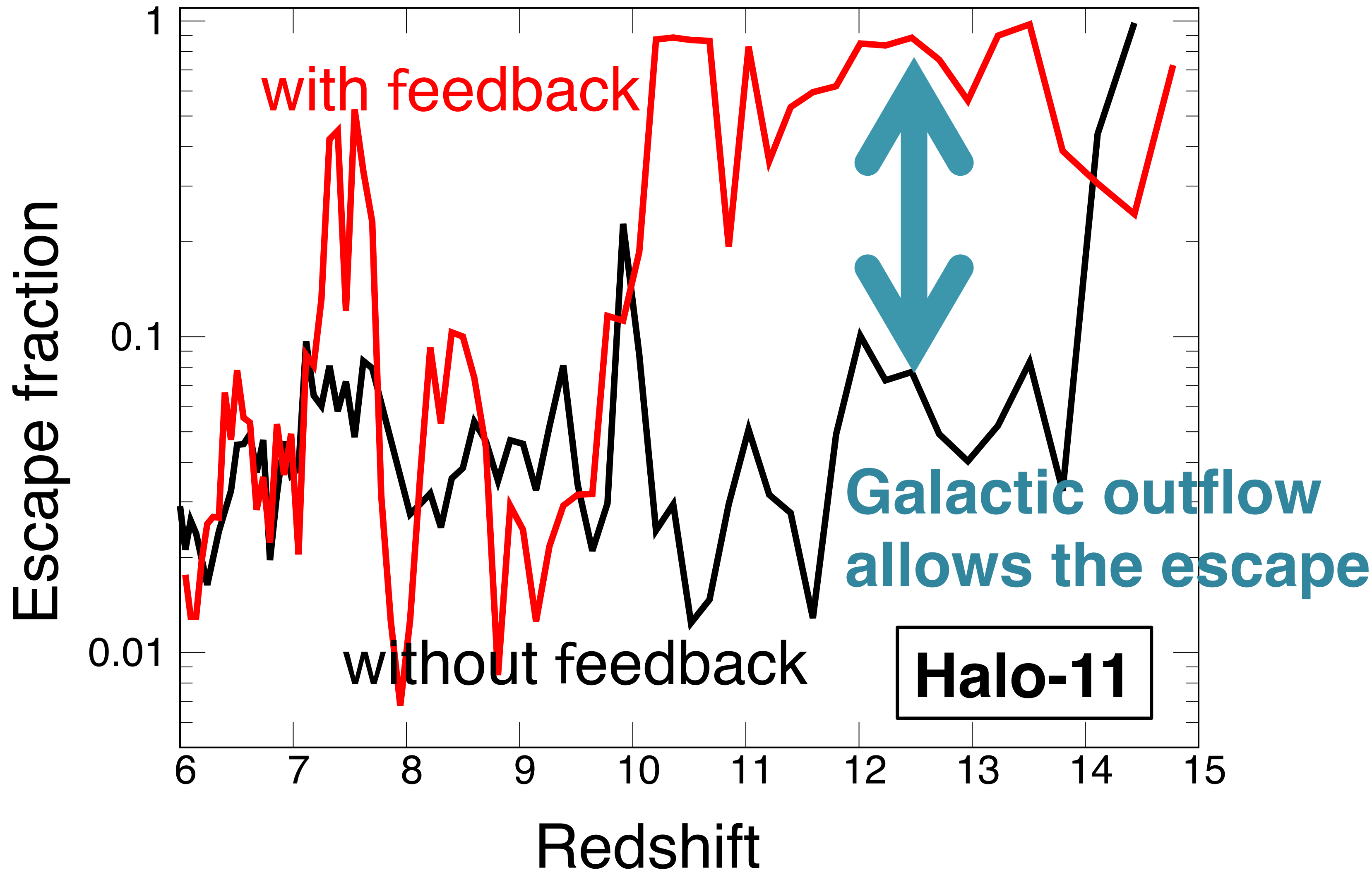




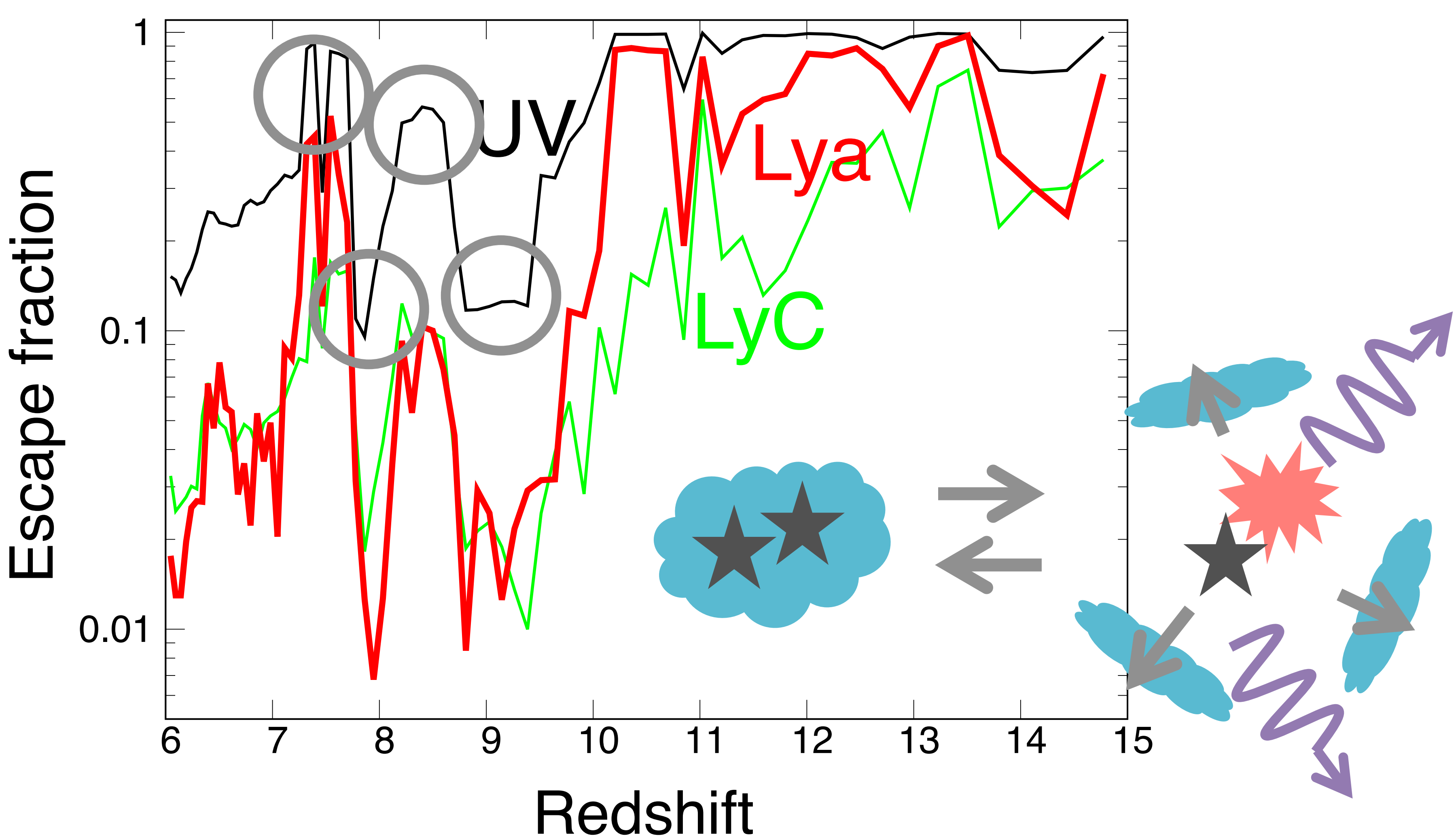
f_{esc} of massive halos



Lya escape fraction



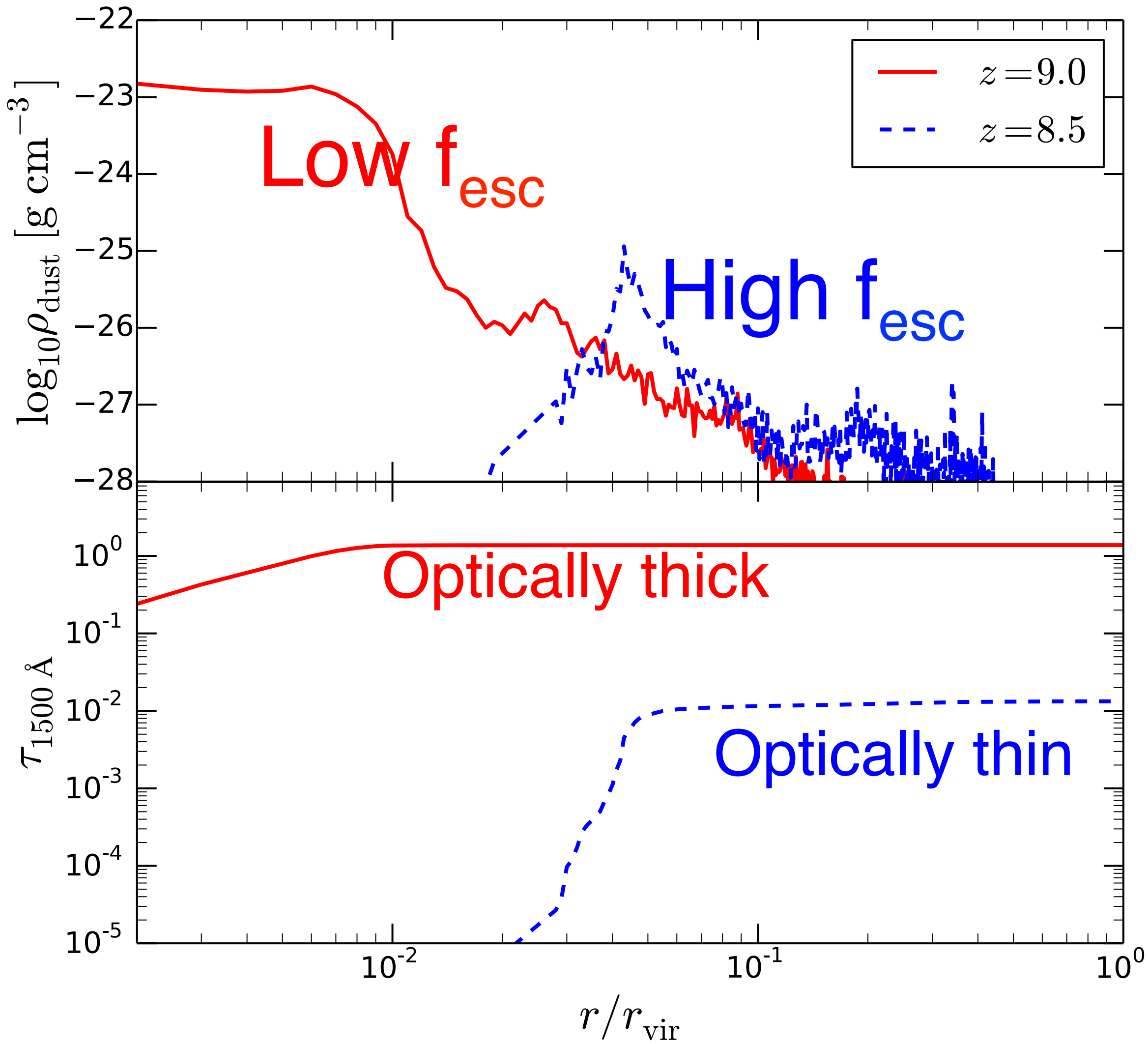
Escape of UV, Lya, LyC photons



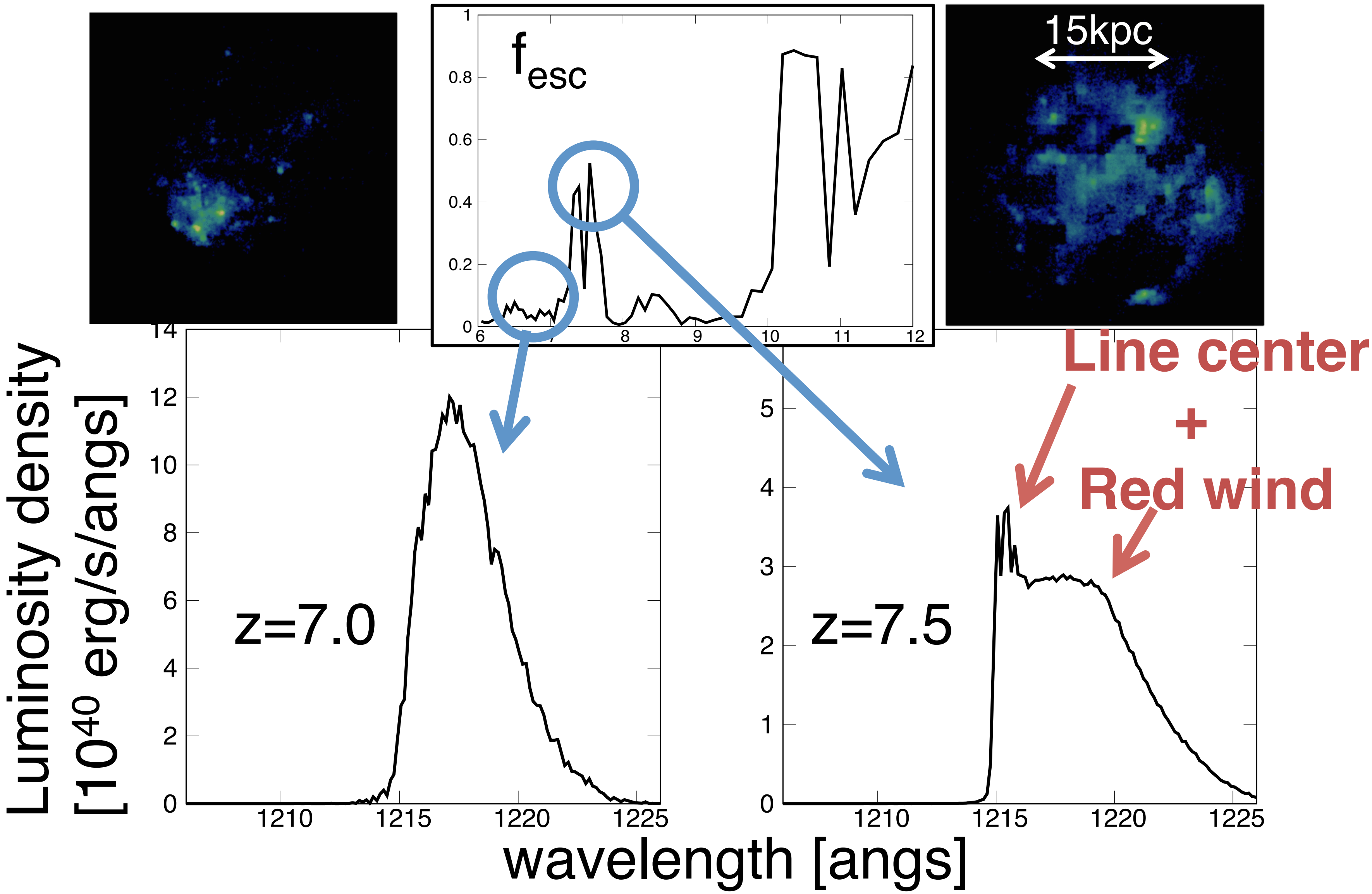
Optical depth

Density profile of dust

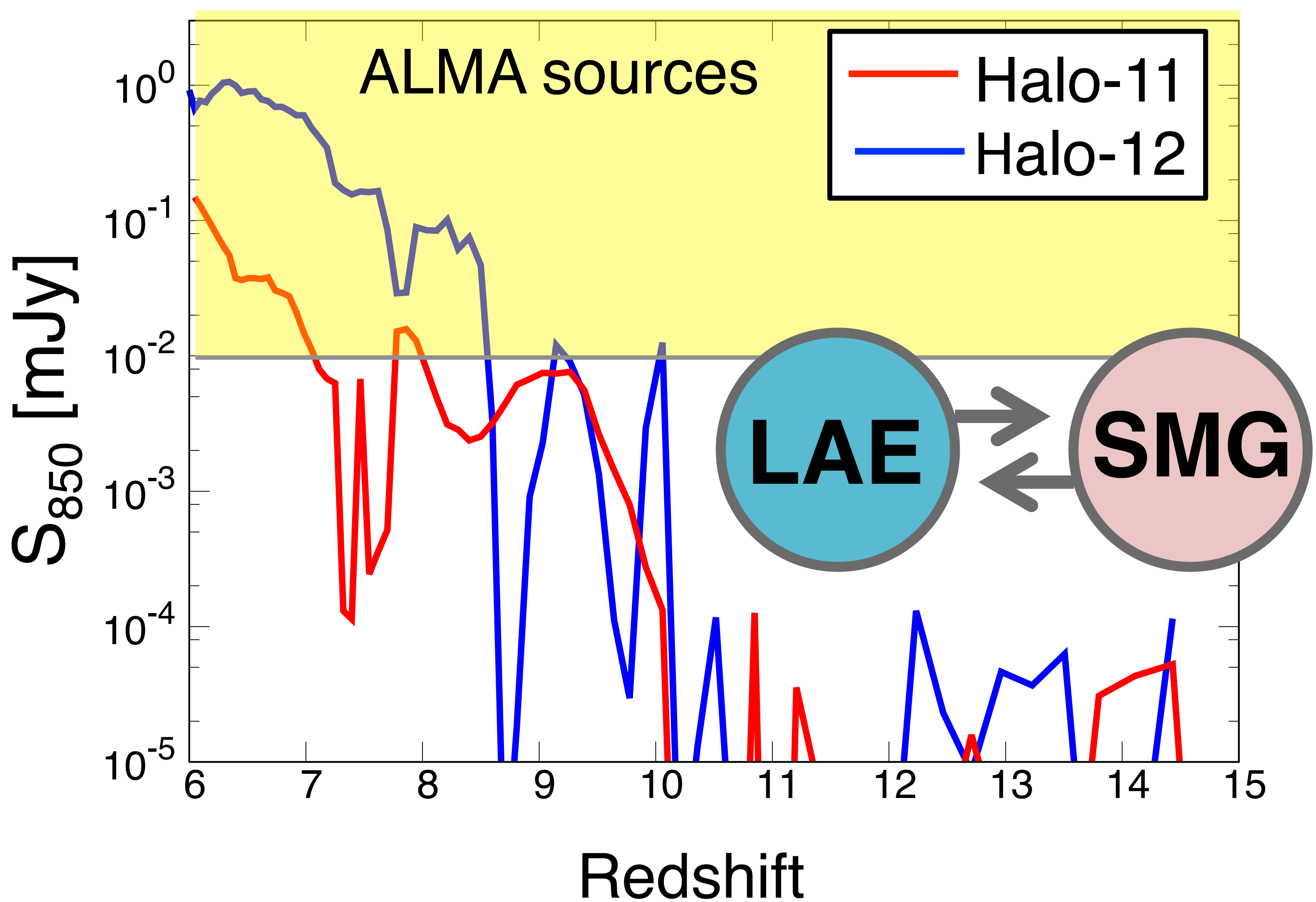
Optical depth for UV cont.



Lya line profiles



Sub-mm flux

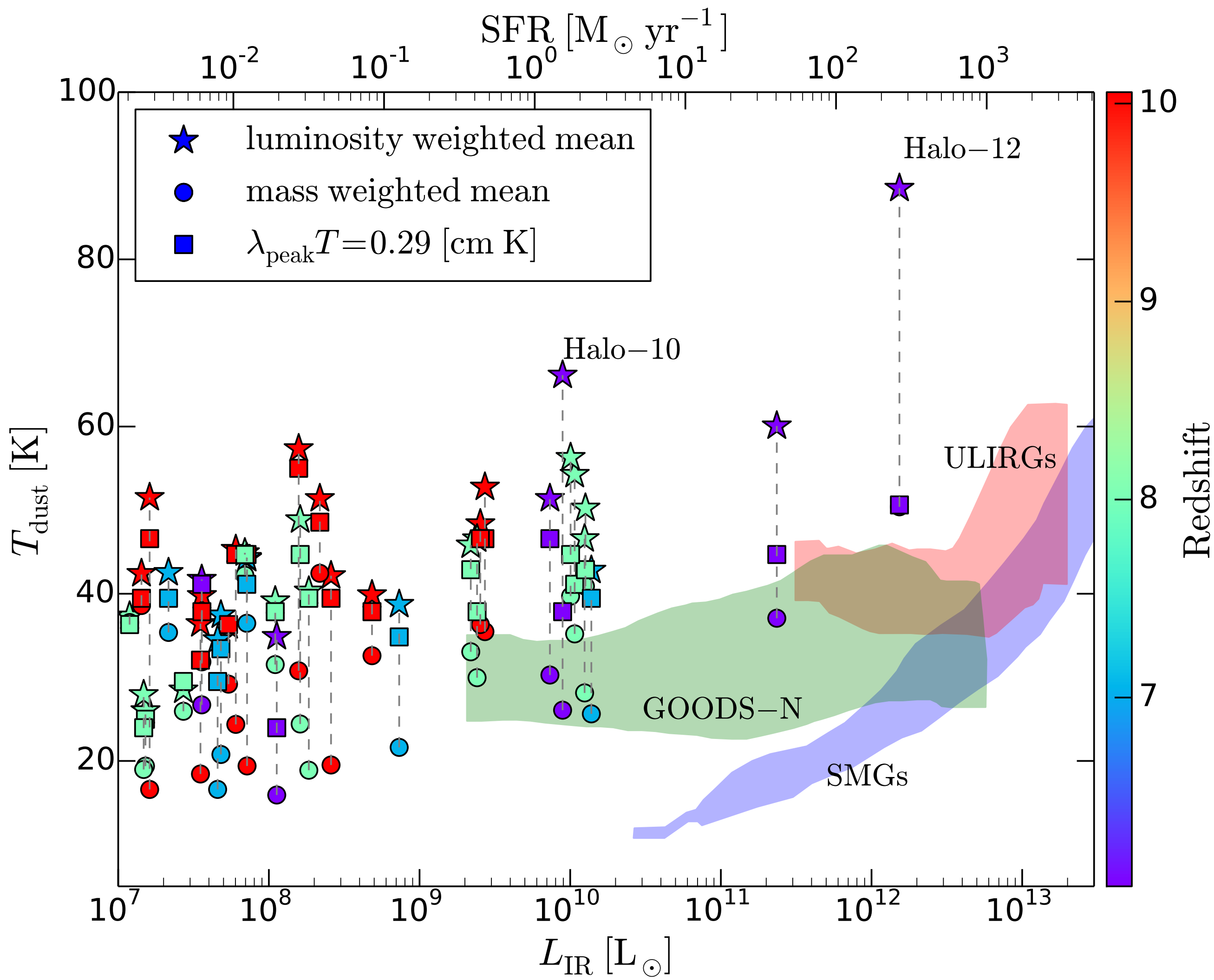


ALMA sources
Halo-11
Halo-12
LAE
SMG
S_{850} [mJy]
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
6
7
8
9
10
11
12
13
14
15
Redshift

Dust temperature

Shohei Arata's poster

10F



Summary

We study radiation properties of first galaxies by combining cosmological simulations and multi-wavelength radiation transfer calculations

1) **Star formation proceeds intermittently in low-mass halos with Mh < $10^{10}M_{sun}$**
2) **Massive halos become bright (~10^{43}erg/s) and extended(~30kpc) Lya sources at z~6**
3) **UV/Lya escape efficiently in outflow phases (f_{esc}>10%) due to supernova feedback**
4) **Galaxies show the cycles between UV and IR bright phases**