Properties of Very High-z Galaxies

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Abstract

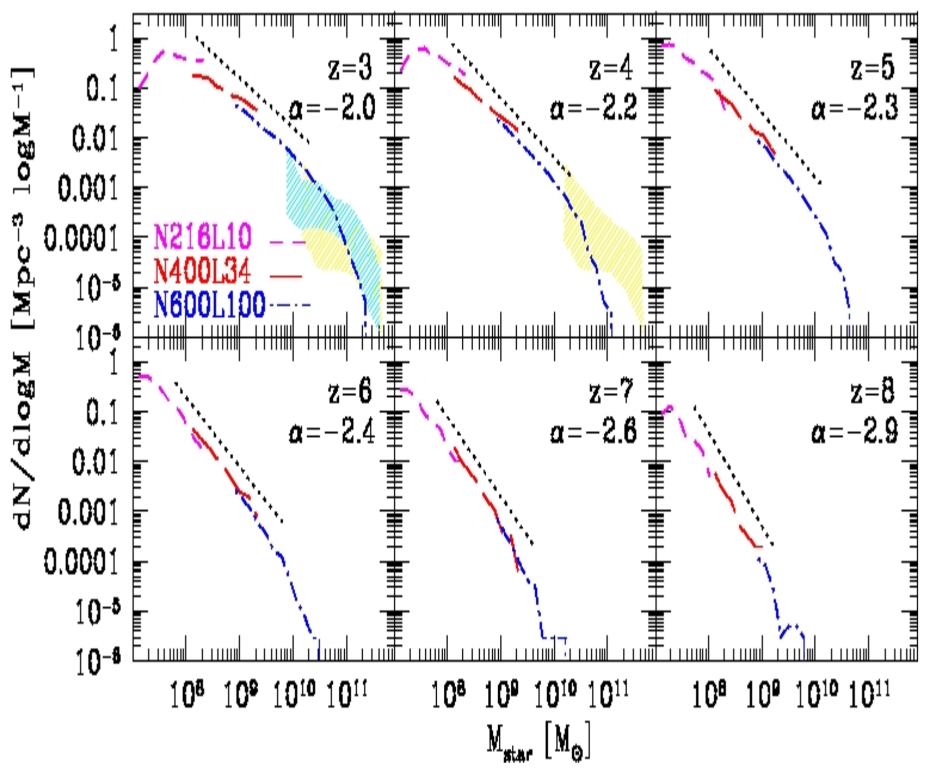
Using cosmological SPH simulations based on the concordance ΛCDM model, we demonstrate that the Galaxy Stellar Mass Functions (GSMFs) and UV Luminosity Functions (UV LFs) shows very steep low-mass end slopes of ($\alpha < -2$) for high-z galaxies. This finding suggests that the galaxy stellar mass evolution is significantly faster at high-z. Using a high resolution simulations with Constrained Realizations method, we study the detail properties of high-z galaxies in overdense regions. The simulations show that these galaxies are mostly gas-rich disks that grow their stellar mass very rapidly. This is in contrast with the low-z morphology-density relation. We also study the metals evolution in these objects.

Simulation

- Gadget-3 : TreePM for gravity solver and SPH for Hydrodynamics (Springel 2005)
- H, He, and metal cooling, and tabulated UVB heating (Choi & Nagamine 2009)
- Sub-resolution model of, multiphase ISM, Star formation (Choi & Nagamine 2010), SNe feedback, phenomenological model for galactic winds (Choi & Nagamine 2011).
- Cosmology: 5th year WMAP best-fit values (Komatsu et al 2011)

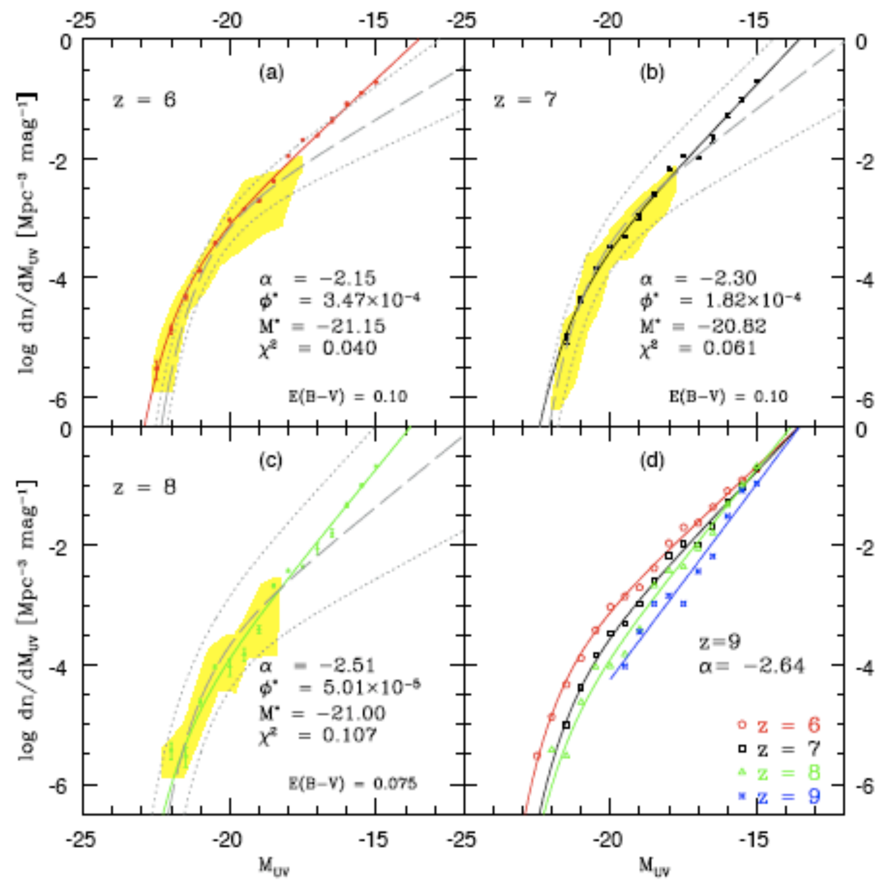
Statistical Properties of High-z Galaxies

GSMF



- Composite GSMF (Choi & Nagamine 2012)
  - Compose from three different resolution and volume simulations
  - Can overcome resolution limit and sampling limit
- ***Very steep low mass end of GSMF $\alpha < -2$. And the slope gets steeper as higher re-shift.***

UV LF



Procedure

- Stellar content and star formation history of the galaxies from simulations
- Population synthesis – Bruzual & Charlot 2007
- Dust extinction - Calzetti (1997)
- Apply HST filter function

Result (Jaacks et al. 2012)

- Simulated UVLF shows very steep low-mass end
  - ***$\alpha < -2$ and decreases with redshift increases***
- Good agreement at massive part and marginal agreement at low-mass end.

Properties of z~10 galaxies

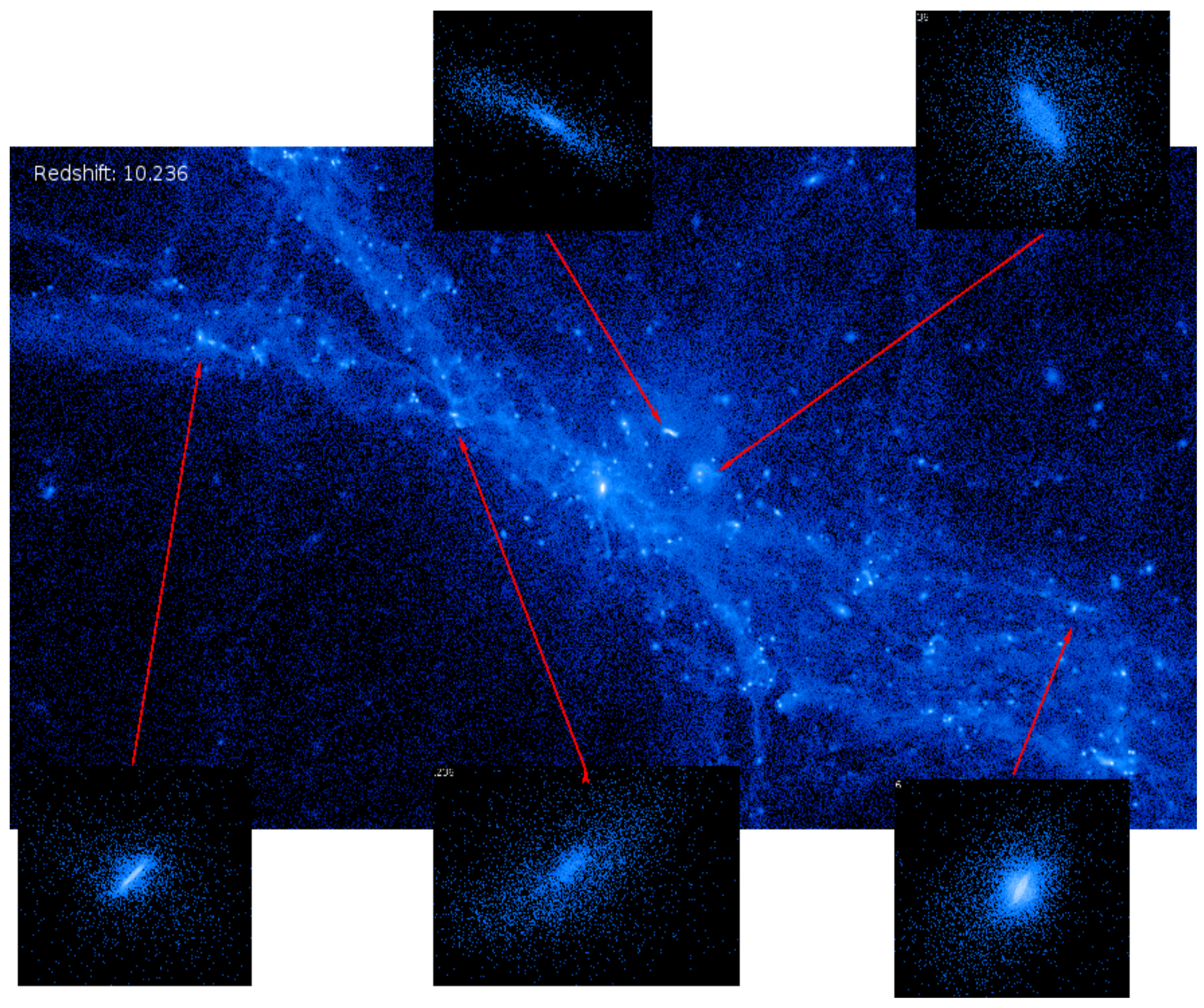
Limitations to simulating high-z galaxies

In order to study high-z galaxy in detail we need to implement high-resolution (high-z galaxies are small) and large-volume (high-z galaxies are rare; only in over-dense regions) simulations.

Constrained Realization

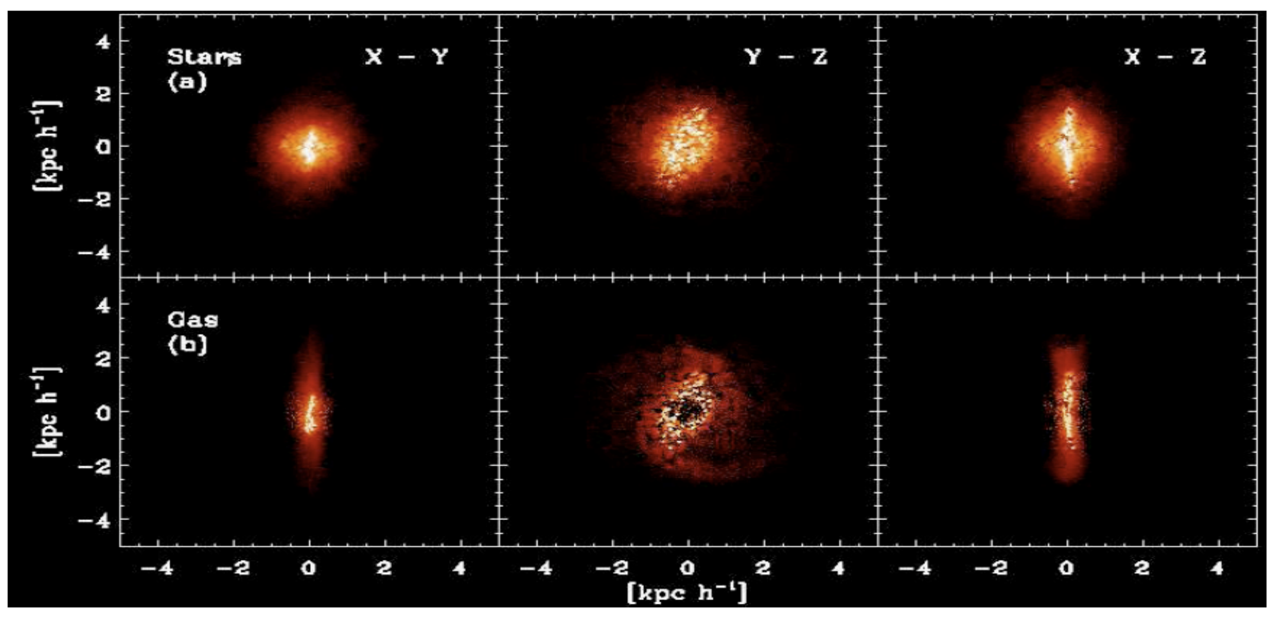
- Initial conditions : Constrained Realizations of Gaussian random fields : construct random realizations which obey any number of imposed constraints (Hoffman & Ribak 91)
- Add three level zoom-in
- Design to build z~6 QSO site (1 in 2Gpc^3 comoving volume) in 20Mpc^3 simulation domain
- Achieve 4.7x10^5 M_{sun} DM particle and 1x10^5 M_{sun} gas particle resolution for

Prevalence of gas rich disks

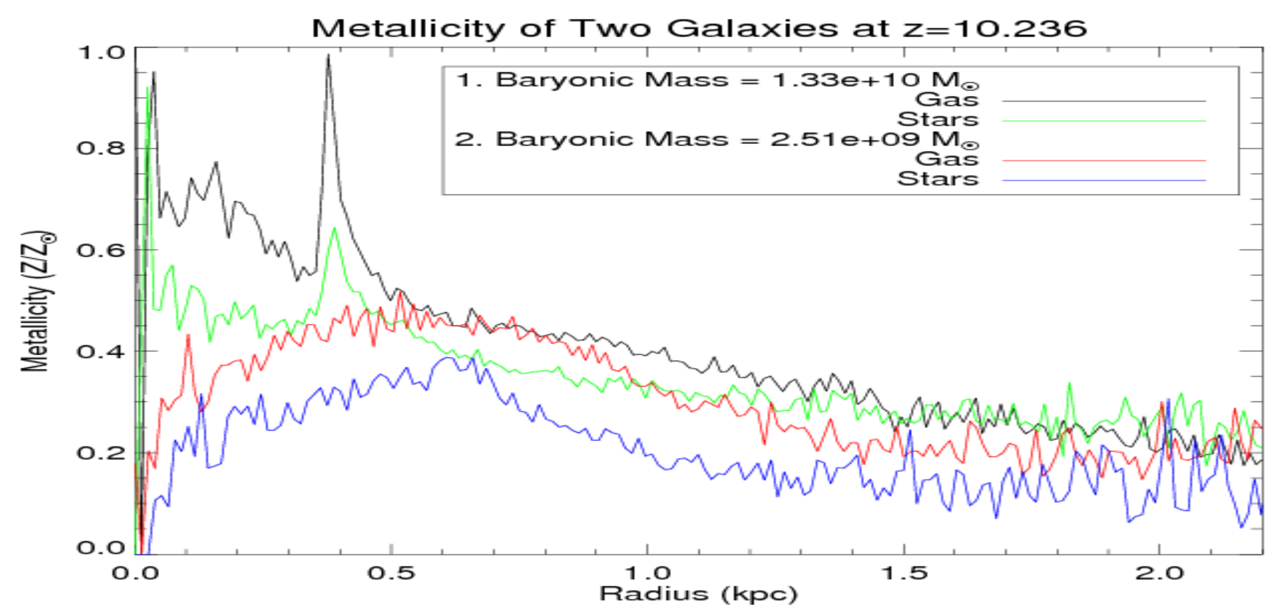


Gas density distribution of the high-resolution region in simulation at z~10.236. Figure also shows zoomed view for selected massive galaxies at the insets. All massive galaxies in the simulation appear to be gas-rich disks. Gas fractions can exceed or be ~30%. In addition, these objects reside in a high gas density region.
(E. Romano-Diaz, J.-H. Choi, I. Shlosman & M. Trenti)

Disk at z~10



Zoom-in views of one of the selected massive disk in the left figure. Gas component clearly shows disk shape with clear bar and spiral feature. Stellar component shows rather spherical shape. (Romano-Díaz et al 2011)



Radial metallicity for two sample of z~10 galaxies. First galaxy is the same galaxy shown above. Gas metallicity is generally higher than stellar metallicity. The metallicity gradually decreases with radius increase. Surprisingly, metallicity at the inside of massive galaxy reach to solar value.

These gas-rich disks form rapidly and remain resilient during this epoch of a fast growth of galactic stellar masses

Discussion

Steep low-mass end

- LF integration is diverge : need a galaxy low-mass cut (10^7M_{sun})
- Reionization is done mostly by low-mass galaxies
- Rapid galaxy stellar mass increase during this epoch : It is also support by sSFR for a given redshift – high redshift galaxies shows higher sSFR.

Gas rich disks at z~10

- Could result in rapid galaxy evolution
- Contrary to Morphology-Density relationship : All galaxies, > 10^9 Mo in the simulation show disk morphology.

Observational support

- Recent high-z UV LF support steep mass-end slope (α~-2)
- Number density of z~10 galaxy in extended survey fields (HUDF09, ERS, and CANDELS) is too low (Oesch et al. 2011)
  - found 1 objects vs estimated 6 objects (empirical estimation from lower redshift observation)
  - Need rapid growth of galaxy number density between z~10 to z~8

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