Towards Modeling Supernovae in Galaxy Formation Simulation

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1. Introduction

Understanding physical processes of galaxy evolution is one of the most important goals in modern astronomy. From Subaru Hyper Supreme-Cam survey data, Harikane et al. (2018) found a tight relation of $SFR/\dot{M}_{\rm h} - M_{\rm h}$ showing no significant evolution beyond 0.15 dex in the wide mass range over redshift $z \sim$ 4-7. This weak evolution suggests that the $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation is a fundamental relation in high-redshift ($z \geq 4$) galaxy formation. In this study, we investigate whether the $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation obtained from observations can be reproduced using cosmological hydrodynamical simulation. SFR and $\dot{M}_{\rm h}$ are related to the time evolution of galaxies, and since materials accreted in galaxies are thought to contribute to star formation through various physical processes, it is important for understanding galaxy formation to verify the relation between these quantities theoretically using cosmological simulation.

2. Method

We use smoothed particle hydrodynamics code `Gadget3-Osaka` [Aoyama et al.(2017), Shimizu et al.(2019)]. We employ four different resolution and volume simulations as summarized in Table 1. We use the `FOF` algorithm and `SUBFIND` algorithm [Springel et al.(2001)] to identify halos and galaxies in simulations (Figure 1).

Table 1: The four different resolution and volume simulations are employed in this study.

Name	Box size (h^{-1}Mpc (comoving))	particle number	gravitational softening length (h^{-1}kpc (comoving))
L100N512	100	2×512^3	6.5
L20N128	20	2×128^3	5.2
L10N128	10	2×128^3	2.6
L10N256	10	2×256^3	1.3

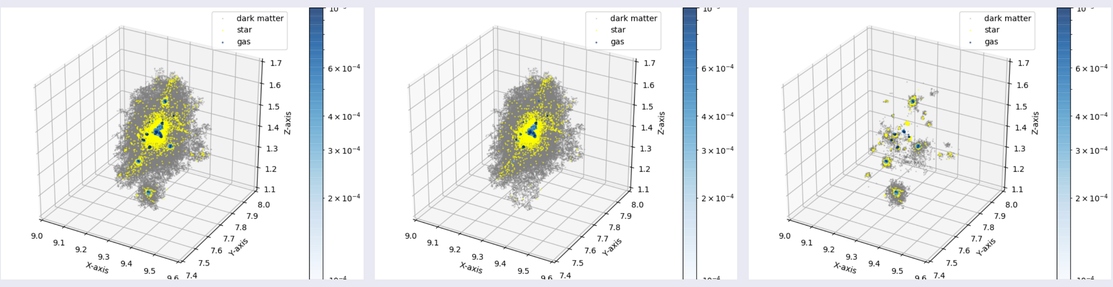

Figure 1: A halo identified by using `FOF` algorithm (left), the central galaxy identified by using `SUBFIND` (center) and the difference of left and center panel (right). Gray points represent dark matter particles, yellow points represent star particles. Blue points represent SFR-weighted gas particles.

3.1. Result1: Dependence on resolution

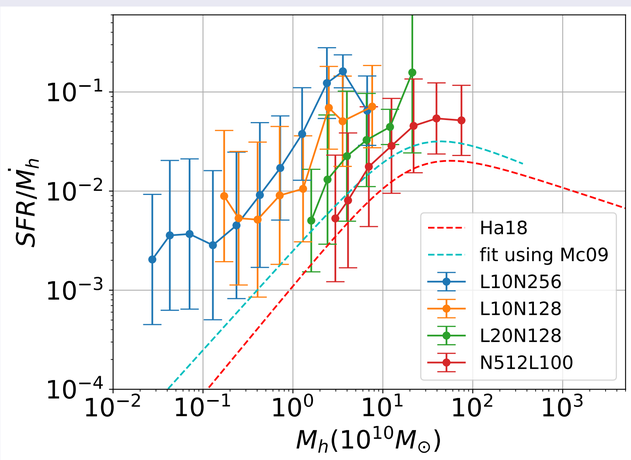

Figure 2: $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation

Figure 2 shows $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation at redshift $z = 6$. $SFR/\dot{M}_{\rm h}$ increases as spatial resolution increases. To identify the reason $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation depends on resolution, we compare other statistical properties with previous studies. Figure 3 shows star forming main sequence compared with Schreiber et al. (2015; Sc15), and figure 4 shows halo mass accretion rate compared with Behroozi et al. (2013;Be13) and McBride et al. (2009;Mc09). These relations do not show resolution dependence and fit with previous studies. Figure 5 shows galaxy stellar mass function and this function show the same trend with $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation.

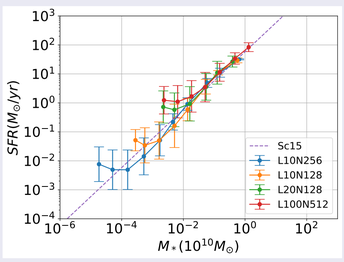

Figure 3: Star-Forming Main Sequence

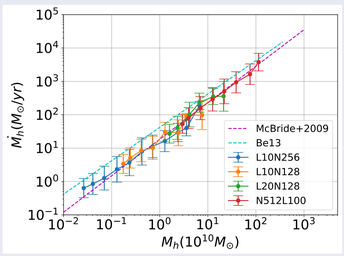

Figure 4: Halo mass accretion rate

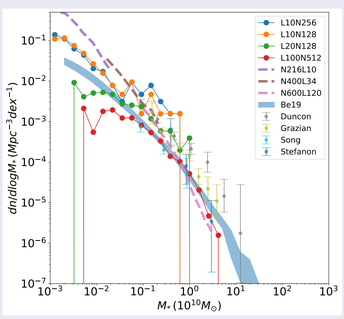

Figure 5: Galaxy stellar mass function

3.2. Result2: Effect of supernova feedback and star formation efficiency

Table 2: List of simulations with different parameters compared in this study.

Run name	Notes
L10N128	Fiducial run
L10N128_sfefficiency0005	Fiducial run but star formation efficiency 0.005
L10N128_K70T30	Fiducial run but 70 per cent kinetic feedback and 30 per cent thermal feedback
L10N128_sniieventnumber4nspawn1	Fiducial run but $n_{\rm fb} = 4$, $n_{\rm spawn} = 1$

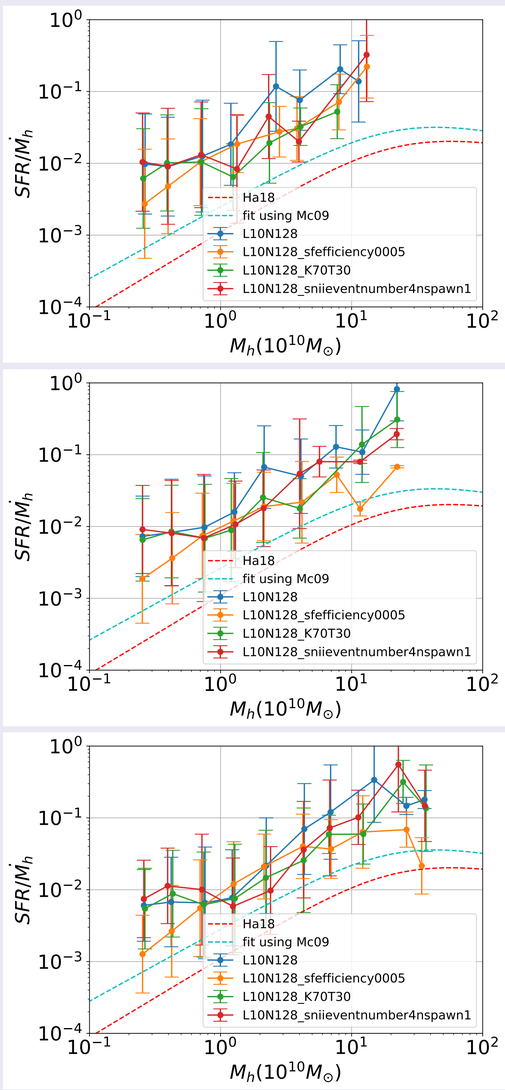

Figure 6: $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation at z =6 (top), 5 (middle), 4 (bottom)

We run a series of simulations as summarized in Table 2 to investigate the relation between resolution, star formation efficiency and feedback. The parameters of our fiducial run is as follows: star formation efficiency is 0.05, 30 per cent kinetic feedback and 70 per cent thermal feedback, number of feedback event number $n_{\rm fb}$ is 8 and number of star particles spawn from a gas particle $n_{\rm spawn}$ is 2. Figure 6 shows the redshift evolution of $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation. We find that star formation is suppressed by increasing the energy released by single supernova (L10N128_sniieventnumber4nspawn1) and by increasing the ratio of kinetic feedback (L10N128_K70T30). This suggests that the effect of blowing gas by kinetic feedback suppress star formation more effectively than thermal feedback. We also find that our results show the decreasing trend of $SFR/\dot{M}_{\rm h} - M_{\rm h}$, which is opposite to Behroozi et al. (2013).

4. Summary

Our results are summarized below:

1. We investigate whether the $SFR/\dot{M}_{\rm h} - M_{\rm h}$ relation obtained from observations can be reproduced using cosmological hydrodynamical simulation. However, our simulation results show resolution dependence, and the result of high resolution simulation show higher SFR compared with observation.
2. We run a series of simulations as summarized in Table 2 to investigate the relation between resolution, star formation efficiency and feedback. We find star formation is suppressed by change of parameters, but our result still have higher SFR compared with observation.

5. Further work

We find our simulation has dependence on resolution, and one major reason of this depencency is the modeling of supernovae. Now we are trying a new scheme of modeling supernovae. And also, now we are studying about blast wave of supernovae and its effect on ISM.

References

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