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 Suprime-Cam survey data, Harikane et al. (2018) found a tight relation of \( SFR/M - M_h \) 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 \( SFR/M - M_h \) relation is a fundamental relation in high-redshift \((z \geq 4)\) galaxy formation. In this study, we investigate whether the \( SFR/M - M_h \) relation obtained from observations can be reproduced using cosmological hydrodynamical simulation. \( SFR \) and \( M_h \) 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 Gadget-3-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.

<table>
<thead>
<tr>
<th>Name</th>
<th>Box size (h^{-3}Mpc (comoving))</th>
<th>particle number</th>
<th>gravitational softening length (h^{-1} kpc (comoving))</th>
</tr>
</thead>
<tbody>
<tr>
<td>L100N512</td>
<td>100</td>
<td>2 × 512^3</td>
<td>6.5</td>
</tr>
<tr>
<td>L102N128</td>
<td>20</td>
<td>2 × 128^3</td>
<td>5.2</td>
</tr>
<tr>
<td>L102N128</td>
<td>10</td>
<td>2 × 128^3</td>
<td>2.6</td>
</tr>
<tr>
<td>L102N256</td>
<td>10</td>
<td>2 × 256^3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

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. Result1: Dependence on resolution

Figure 2 shows \( SFR/M - M_h \) relation at redshift \( z = 6 \). \( SFR/M_h \) increases as spatial resolution increases. To identify the reason \( SFR/M - M_h \) 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 \( SFR/M - M_h \) relation.

4. Summary

Our results are summarized below:

- We investigate whether the \( SFR/M - M_h \) 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.
- 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 \( n_{Fe} \) is 8 and number of star particles spawn from a gas particle \( n_{spawn} \) is 2. Figure 6 shows the redshift evolution of \( SFR/M - M_h \) relation. We find that star formation is suppressed by increasing the energy released by single supernova (L101N128_withinbody4nspawn1) and by increasing the ratio of kinetic feedback (L101N128_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 \( SFR/M - M_h \), which is opposite to Behroozi et al. (2013).

5. Further work

We find our simulation has dependence on resolution, and one major reason of this dependency 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