Exploring How Variations in Cosmological Initial Conditions Affect the `Simba-C` Simulation

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Abstract

We look at the effect IC's have on the Simba-C cosmological simulation. We changed the dark matter content of three simulations and looked at the matter density distribution and global properties of the changed simulations. We saw a concentration of the total matter density into the LSS as we increased the dark matter. This lead to an increase in star formation rate, which in turn led to an increase in metallicity and blackhole mass. Thus IC's lead to differences in the matter composition of the simulations as well as differences in their global properties. Small differences in IC's behave as we would expect.

Introduction

Cosmological simulations help us test and understand our models of galactic evolution, as well as the effect feedback processes have on galaxies. An important input into these simulations are the initial small variations in the largly uniform cosmological background. These initial conditions (IC's) are the seeds that later evolve, through gravity, into the large scale structure (LSS) we see today.

Testing the effect IC's have on cosmological simulations is important to deepen our understanding of our models of galactic evolution and feedback processes. This can also be used as another method of comparison between different models to test how the models treat small variations of IC's. Variations in the IC's can also be used to see their effect on the evolution of the LSS.

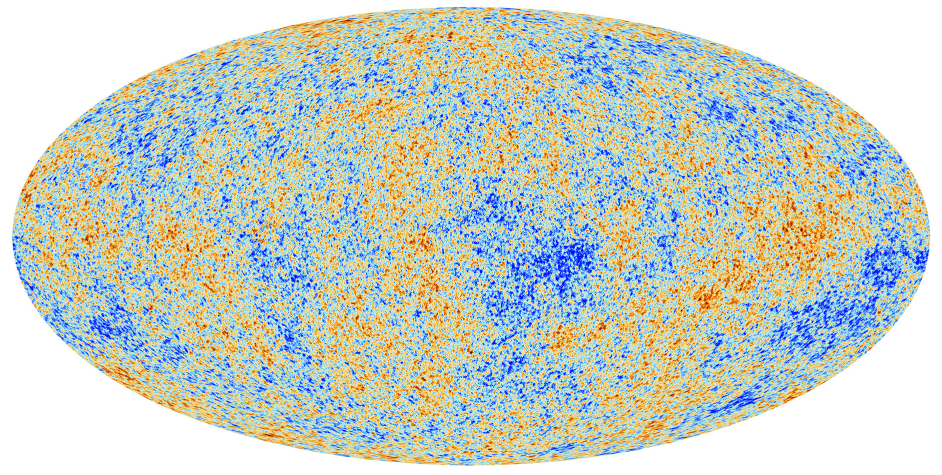

Figure 1: Cosmic Microwave Background as seen by Plank.

Methodlgy

We first tested the variation of the total matter density parameter Ω_m, while keeping the baryonic matter density Ω_b constant, in effect only changing the dark matter content of the simulations. We also kept a flat geometry by getting our dark matter from the equation $\Omega_\Lambda = 1 - \Omega_m$. We chose Ω_m values of 0.11, 0.27, 0.45. These values were chosen above and below the 0.27 value that we get from plank 2018, and far enough a part to see a large difference.

- First we feed our values to the CLASS code to get our matter power spectra. As seen in Figure 2.
- Then we give these spectra to the MUSIC program to create the IC'c for our simulation.
- Lastly we run our Simba-C cosmological simulation with our IC's and analyse our output.

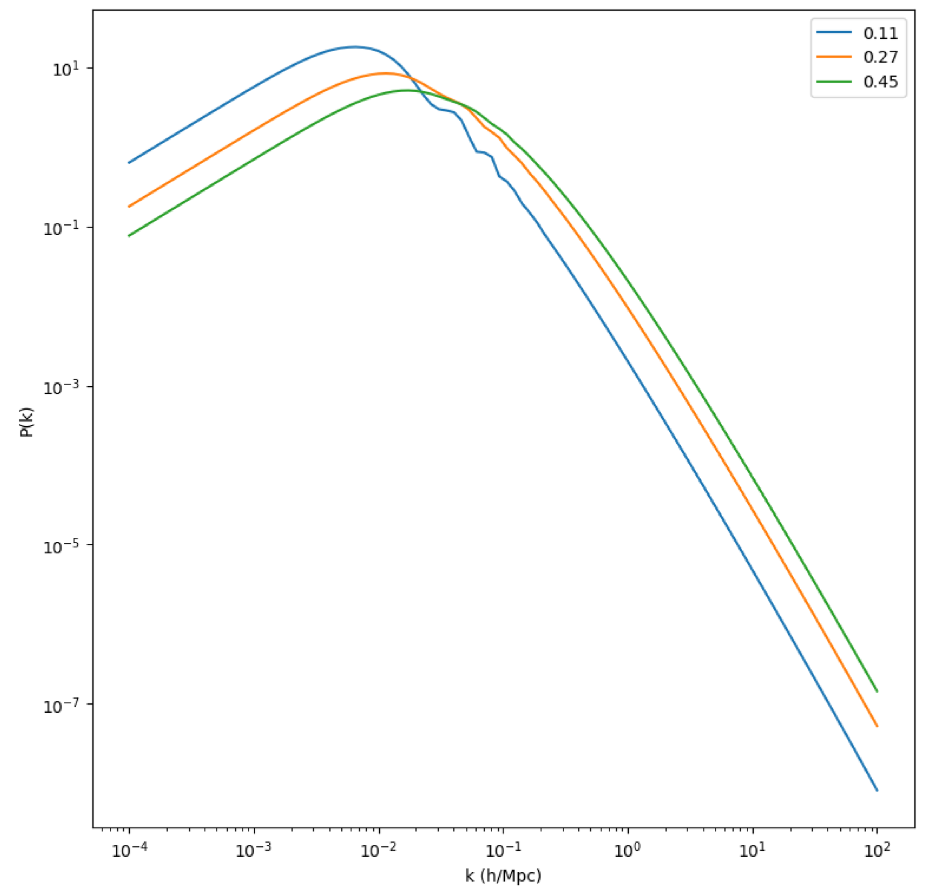

Figure 2: Matter Power Spectra from CLASS with total matter density of 0.11 (blue), 0.27 (orange) and 0.45 (green).

Results

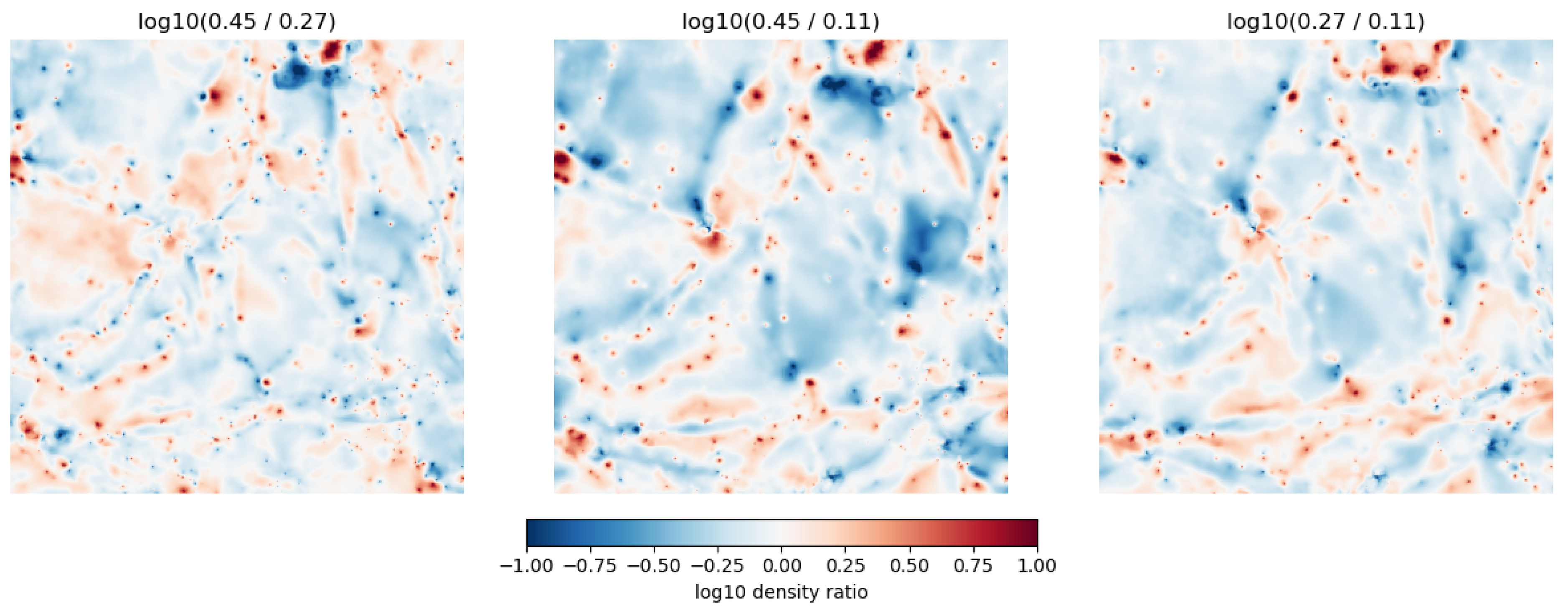

Figure 3: Log of the total matter density differences between simulations with 0.45 and 0.27 dark matter density (left), with 0.45 and 0.11 dark matter density (centre) and with 0.27 and 0.11 dark matter density (right).

Figure 3 Discussion

- Shows the matter density differences between the three simulations with different amounts of dark matter.
- The **Centre** graph shows the largest difference between the 0.45 and 0.11 simulations.
- We see that as we increase the dark matter content of the simulations, the LSS (red) gets more concentrated.
- The voids (blue) become less concentrated.
- This is what we would expect, because dark matter forms the scafolding of the LSS.
- As we increase the dark matter, more matter is attracted and clumps together.
- The LSS becomes more concentrated.

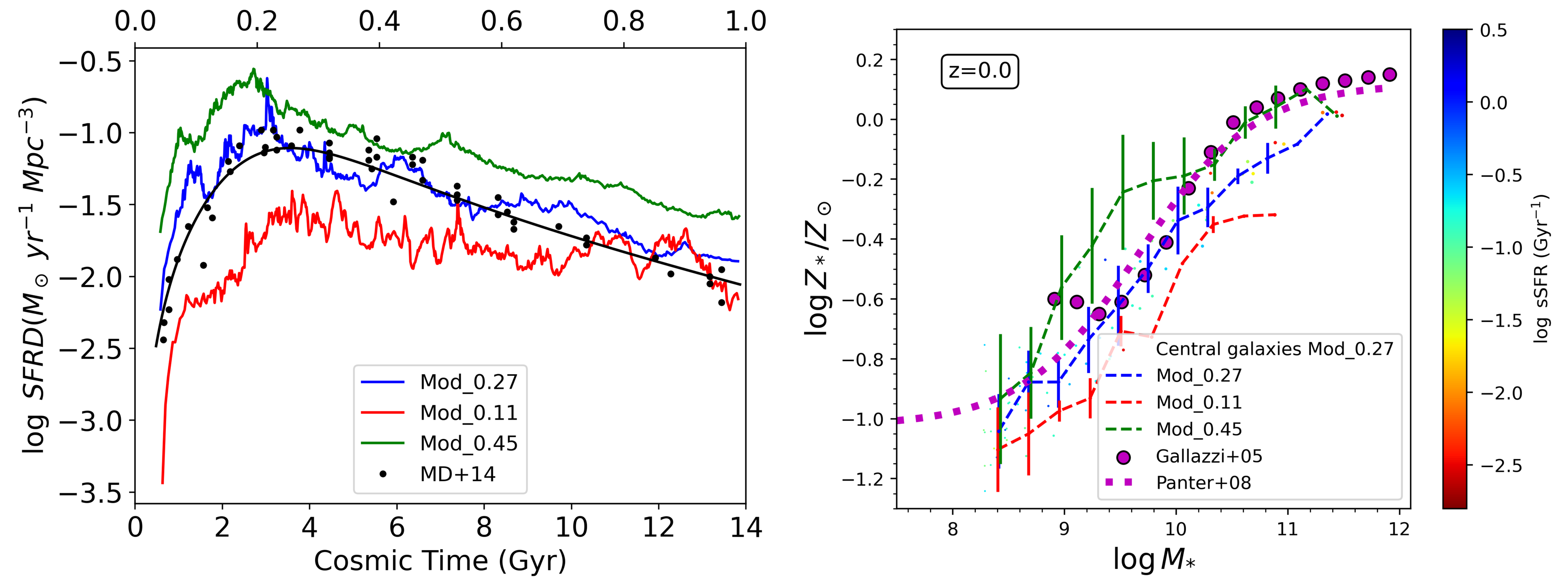

Figure 4: Graphs showing the global statistics of the three different simulations. (Left) log of the star formation rate density vs Cosmic time. (Right) Stellar mass–stellar metallicity relation at z = 0.

Figure 4 Discussion

- The **Left** graph shows the star formation rate (sfr) across cosmic time.
- The 0.45 simulation has the highest sfr and the 0.11 simulation has the lowest.
- The 0.11 simulation also has very low sfr at early cosmic time.
- This is what we would expect because as we increase dark matter, gas becomes more clumped together which allows for more star formation.
- The **Right** graph shows the stellar mass to stellar metallicity relation.
- Again the 0.45 simualtion has the highest metallicity and the 0.11 has the lowest.
- From theory we know that with increased sfr, stars form quicker and make more metals, thus we see an increase in stellar metallicity.
- The increase in dark matter also attracts these more metal rich gasses into the LSS.

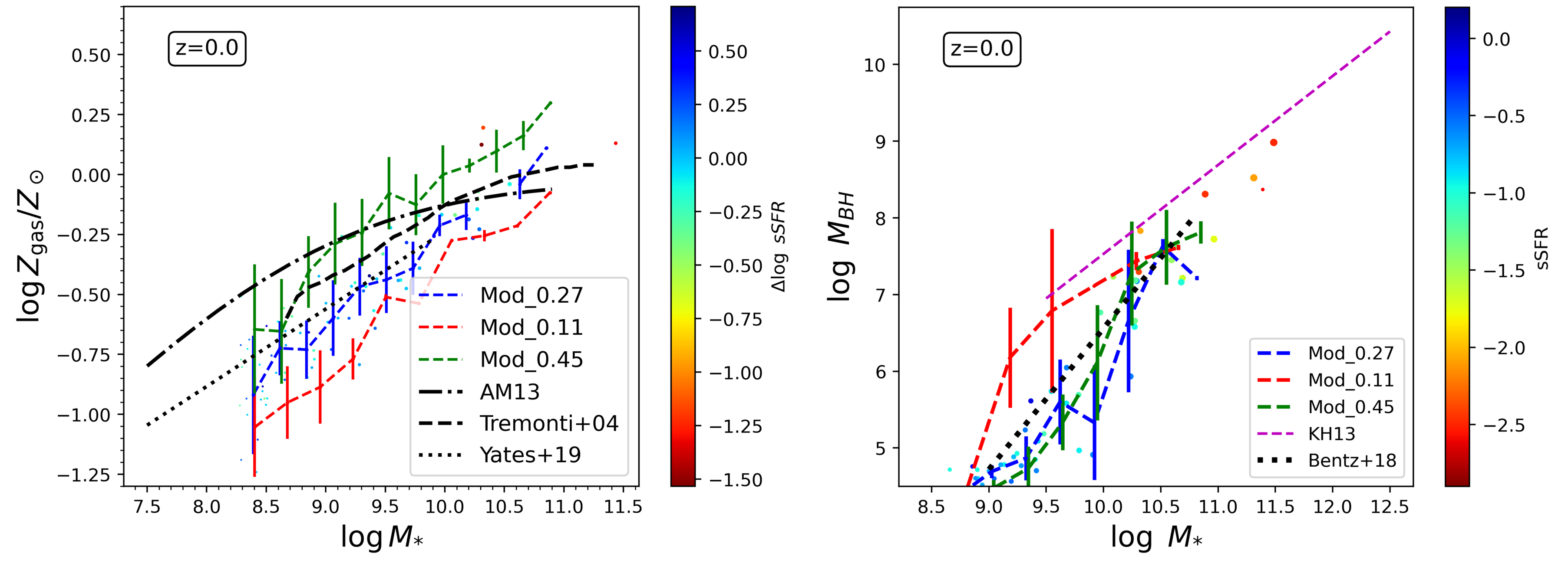

Figure 5: Some more graphs showing the global statistics of the three different simulations. (Left) Gas–phase mass–metallicity relation at z = 0. (Right) Stellar mass - Blackhole mass relation at z=0.

Figure 5 Discussion

- The **Left** graph shows the Gas-phase mass - metallicity relation.
- Similar to the stellar mass to stellar metallicity relation we see that the 0.45 simulation has the highest metallicity and the 0.11 has the lowest.
- This is due to similar reasons as the stellar mass to stellar metallicity relation in Figure 4 Right.
- The **Right** graph shows the stellar mass - blackhole mass relation.
- We see the 0.45 simulation has the highest blackhole mass and the 0.11 simulations has the lowest.
- Due to the higher sfr and the increased attraction of the dark matter, we have more stars in closer proximity to each other. This leads to more blackhole formation which leads to an increase in blackhole mass.

Key Conclusions

- As the dark matter density in the three different simulations increased we saw an increase in the concentration of the total matter density.
- This lead to an increase in sfr, which in turn led to an increase in metallicity and blackhole mass.
- This indicates that IC's have a measureable effect in simulations. And that small differences in the IC's behave as we would expect.

Future work

- Test other parameters, e.g. Ω_b, σ_8, A_s, H_0 and n_s, to see what their effects will be.
- Include filament identification to compare the resulting structures at late times.
- Make matter power spectra at late times for the different simulations to compare.

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