MPhys Project Summary:Dissecting the key correlation between galaxies and their dark matter haloes: Mass or Structure?

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1 Introduction

It is believed that our current universe began from a very uniform structure. However, due to tiny quantum fluctuations and gravitational attraction, the dark matter particles continuously merged together over very long time eventually forming dark matter haloes. Within the gravitational potential of the dark matter haloes, the visible baryonic matter cooled down and condensed within haloes. Over time, baryonic matter formed galaxies within parent dark matter haloes (Figure 1).

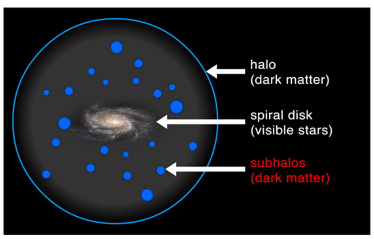

Figure 1: Diagram Showing a Galaxy Formed Inside a Halo

There are many different types of galaxies, disks, spheroids lenticulars and many others. However, despite the rich diversity of galaxies there have been observed very tight scaling relations between galaxies and haloes. These scaling relations link various galaxy and halo properties. One of the most prominent relations is the relation between the halo radius and galaxy radius. Kravtsov et al found that a linear normalisation between the galaxy radius and halo radius reproduced the observed data well.

In our work we propose an original methodology to populate haloes with galaxies by using the Kravtsov relation to assign stellar mass from the galaxy radius - "The Reverse Method". We compare our method of assigning stellar mass to the more traditional approach of abundance matching, which populates galaxies with stellar mass from the halo mass of the parent halo. In so doing, we explore which of the two methods reproduces the data observed in the Universe from the Sloan Digital Sky Survey (SDSS). The properties compared are: The Size function: The number density of galaxy sizes. The Stellar Mass Function (SMF): The number density of galaxy stellar mass. The clustering of galaxies: The property which shows how randomly distributed the galaxies are. The final Stellar Mass - Halo Mass Relation (SMHM): The relation showing how haloes are mapped to galaxies.

2 Abundance Matching

The traditional abundance matching method is a statistical method which connects the number density of halo masses - Halo Mass function (HMF) to the number density of stellar masses (SMF). It is found that the SMF of the observed Universe has two distinctly different gradients. Hence to transform the HMF to the observed SMF using a parametric equation it needs to be a broken double power law. This broken double power law equation is our Stellar Mass Halo Mass Relation (SMHM). The parameters of the equation were optimised until it transformed the HMF of the mock catalogue to the SMF which is identical to the SMF of the observed data.

3 Reverse Method

In the Reverse Method we populate haloes with galaxies using the galaxy radius. We take cuts of stellar mass 9.0-9.5 — 9.5-10.0 — 10.0-10.5 — 10.5-11.0 — 11.0-11.5 — 11.5-12.0. We use our derived SMHM relation to roughly calculate the corresponding halo radius boundaries. Once we have the haloes within the stellar mass bin we calculate the galaxy radius by applying the Kravtsov relation. In this relation we have two free parameters the A_k normalisation and the scatter σ_k. We also slightly adjust the halo boundaries and the A_k, σ_k parameters until our mock size function matches the observed size function.

We found that the scatter decreases for large galaxies and increases for small galaxies. This suggests that the scatter in the high mass end is caused by the physical mechanisms from the SMHM. We assign stellar mass directly from distributions of SDSS. For example, in case of a halo with radius of 280 kpc, this value falls within the 265-400 kpc halo radius boundary corresponding to the Stellar mass cut

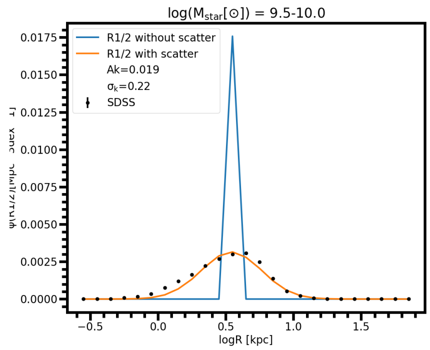

Figure 2: Varying Parameters of The Reverse Method To Match Size Function Of Observed Data

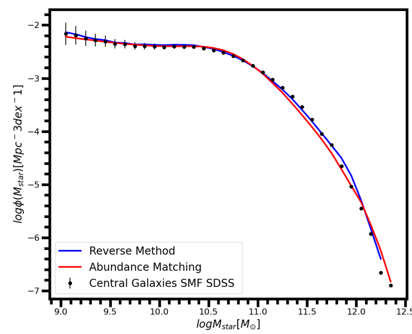

Figure 3: Final SMF of Reverse Method And Traditional Abundance Matching

of 11.0-11.5 $\log(M_\odot)$. Hence we apply a normalisation of A_k=0.018 to calculate the galaxy radius such that it matches the size function of SDSS (Figure 2). Therefore, the galaxy radius for a mock galaxy will be 0.018*280=5.04 kpc. We take the log of this value (0.71) and find the size bin corresponding to SDSS. In this case it would be 0.7-0.8 kpc. We assign a mass randomly such that the distribution of mock masses matches the distribution from SDSS.

4 Results

In the Reverse Method we varied our parameters until we matched the size function of SDSS. We calculated the corresponding SMF and found it to be in a reasonable agreement with the observed SMF of the SDSS data (Figure 3). The last step was to compare the clustering. We did this by taking cuts of stellar mass and calculating the corresponding clustering. We found that the clustering was well reproduced except for high stellar masses. We explain this result by the large scatters needed to match the size functions of SDSS. Furthermore, the final SMHM relation was quite different from abundance matching SMHM. On the other hand, the traditional abundance matching approach where galaxy mass was assigned from halo mass was able to reproduce the clustering and the SMF.

5 Conclusion

The two methods are fundamentally different. We started by matching the size functions and reproduced the SMF and clustering at the low mass end. The final SMHM from the Reverse Method was different from abundance matching. However, when we changed our parameters to match the SMHM from abundance matching we found that this came at the sacrifice of the SMF and the size function.

We also found that large scatters were needed for low mass galaxies suggesting that these scatters were caused by other physical mechanisms not arising from the shape of SMHM. Therefore, based on our results we suggest that the traditional approach assigning stellar mass from halo mass is more fundamental than galaxy size. This perhaps could be understood in terms of the virial theorem, where the halo mass causes the attraction of other particles. This is a more general method of modelling and applies to all galaxy types, whereas the Kravtsov relation is based upon galaxy size being set from the angular momentum of the dark matter and baryons which is appropriate for disk galaxies only. In our work, however, we applied the Kravtsov relation to all galaxies. Our approach has several limitations. One of the major ones is that the parameters changed in the model were not fully optimised to match the observable data. The parameters were changed by hand without an optimisation algorithm, hence there are potentially inaccuracies with the results. Therefore, this work should be considered as an exploratory analysis.