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ABSTRACT
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1 INTRODUCTION

The first objective of this paper is to compare Illustris-1 against the observational results obtained by Jones et al. (2016). In that work the authors study a gas rich sample built with the ALFALFA survey to define the effects of different environments on the gas mass function. The second goal is to extend this environmental classification to the stellar and black hole mass functions. Finally, we study these environmental trends in the baryonica galaxy properties in terms of dark matter halo mass segregation and the dark matter cosmic web.

2 THE ILLUSTRIS-1 SIMULATION

Illustris-1 is a highly resolved cosmological simulation. It reproduces large-scale statistical features of the Universe, such as the galaxy population of massive clusters, as well as small-scale properties such as the morphology of galaxies and detailed values for their stellar and gas content.

The Illustris-1 simulation followed the evolution of 2×1820^3 elements with dark mass resolution of $m_{\rm DM} = 6.26 \cdot 10^6 \rm M_\odot$ and initial baryonic mass resolution of $\overline{\rm m_b} = 1.26 \cdot 10^6 \rm M_\odot$ from a glass-like configuration in a periodic box of 106.5Mpc. The ΛCDM cosmology of this run follows: $\Omega_\Lambda = 0.7274$, $\Omega_{\rm m} = 0.2726$, $\Omega_{\rm b} = 0.0456$, $\sigma_{\rm s} = 0.0809$, $\rm n_s = 0.963$ & $\rm H_0 = 70.4 kms^{-1}Mpc^{-1}$ which is consistent with the (last) Anisotropy Probe (WMAP)-9 **?**. Illustris has a constant spatial resolution of 1.4kpc for DM particles in comoving units, and for baryonic particles it has the same spatial resolution of DM for $\rm z \geq 1$, which is later modified to 0.7kpc in physical units for the rest of the simulation.

This work was performed using the hydrodynamic code AREPO Springel (2010), which combines a moving Voronoi tessellation with the finite volume approach. Included in the evolution algorithm, there are galaxy formation models which account for the evolution of stars and SMBHs. Specifically, the physics followed by this model includes energetic feedback from supermassive black holes and supernovae, as well as stellar evolution and chemical enrichment. This level of detail in Illustris is advantageous for the analysis of the effect of the environment in barionic properties of galaxies. This level of resolution is hard to find among other simulations, i.e. post-processed runs with semi-analytical models which do not directly simulate baryons.(Expand) Describe Arepo more

The output of this simultaion consists of 136 snapshots. 61 of them were taken at $z < 3$ spaced with a cosmological scale factor $\Delta a \approx 0.02$. The remaining 75 were taken at $z > 3$ with spacing $\Delta a \approx 0.01$. Each snapshot was post-processed with a modified version of FOF Davis et al. (1985) to identify DM haloes with more than 32 particles using a linking length of 0.2 times the mean particle separation. Each output group from the 7,713,601 post-processed halos (FOF) is analyzed with the SUBFIND algorithm Springel et al. (2001) to generate, at z=0, and 4,366,546 (sub)halo catalogues with their respective characterization properties.

(HERE TALK ABOUT ILLUSTRIS-2,3 FOR RESOLUTION PURPOSES)

3 THE METHODOLOGY

3.1 Characterizing Mass Functions

To characterize the mass functions in Illustris data we use the Press-Schechter expression

$$n(M) = n_\star \left(\frac{M}{M_\star}\right)^{-\alpha+1} \exp\left(-\frac{M}{M_\star}\right), \quad (1)$$

where n is the number of galaxies per unit volume per dex in mass. This function is fully described by the three parameters: $n_\star$, $M_\star$ and α; $n_\star$ is a normalization factor, the mass scale factor $M_\star$ is that separates the power-law regimen at $M \ll M_*$ and the exponential regimen for $M \gg M_*$. This

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transition graphically resembles a knee, which is the reason why we refer in this paper M_* as the knee-mass. The faint-end slope α is directly related to the exponent of the power-law at the low-mass regime.

This expression comes from a formalism describing the hierarchical formation of gravitationally bound structures in an expanding Friedmann universe arriving to a self-similar state of "equilibrium" for its mass function Schechter (1976). Although its ansatz is not correct **?**, the final expression in Eq. (1) provides a good description of galaxy mass and luminostiy functions **?**.

We also impose a magnitude cut in the r band of $M_r < -19$ to keep a galaxy sample that resembles the one used in previous observational studies. To obtain the Schechter parameters that characterize each numerical mass function, we used MCMC to obtain the fit with best likelihood.

3.2 Resolution Effects

As every simulation, Illustris is subject to limitations due to its numerical finite resolution. The most important limitation in this study is related to its resolution as it puts a constraint on the minimum mass that can be confidently resolved. We use Illustris-2, and Illustris-3, lower resolution versions of Illustris-1 to quantify this effect.

3.3 Environment definitions

In this paper we extend that study observationally-comparable, we follow the 3rd nearest neighbor (3NN) definition of environment proposed by Jones et al.

obtained observationally are supported by a similar analysis in the cosmological simulation Illustris.

For this purpose, we take two approaches to analyze the dependence of mass functions on environment. On one hand, to On the other hand, to confirm our results, we use a computational and theoretical definition of environment (T-Web) of completely different nature proposed by Forero et al. Forero-Romero et al. (2009).

3.3.1 The 3^{rd} nearest neighbor definition of environment

Jones et al. Jones et al. (2016) the SDSS Aihara et al. (2011) catalogue to define the environment of galaxies in the ALFALFA Giovanelli et al. (2005) survey. This SDSS catalogue was chosen to be optically-selected and volume-limited to account for apparent lonely galaxies in ALFALFA with increasinf distance. For this reason, they pre-selected galaxies brighter than $M_r = -18.9$ in this survey.

To quantify the environment , for each reference galaxy in ALFALFA, they calculated the projected distance in the sky to the third nearest neighbor belonging to the pre-selected SDSS catalogue. This projected distance in the sky defines a numeric-surface density for each reference galaxy. To do so, first, they filtrated candidate neighbors by their radial velocity relative to the reference galaxy which had to be within $450km/s$. According to Hubble's law, this effectively restricts the candidate galaxies to a smaller radial range, reducing apparent closer galaxies arising from the use of projected distances.

Once quantified the environment for each ALFALFA galaxy with the distance to the 3rd NN definition, they divided the group in four quartiles according this quantity. For each quartile, the respective HIMF was calculated, and with this, a Schechter fit was obtained.

As we want to replicate as closely as possible the method effectuated by Jones et. al Jones et al. (2016), we use the same specifications to calculate the environment. We perform the analysis of the Schechter functions to gas, DM, stellar and BH mass functions. We do not perform the study directly on HIMFs because this would require some extense calculations. We take the gas mass function as a first approximation.

3.3.2 The cosmic web method

To complement and verify the analysis performed with the third nearest neighbor method, we chose a complementary method of completely different nature. The chosen method was developed by Forero et al. Forero-Romero et al. (2009). It uses the Hessian 2 of the gravitational potential obtained from the smoothened DM density field to classify galaxies into four morphological environments.

$$H \tag{2}$$

Specifically, we diagonalize the Hessian matrix of the gravitational potential ϕ obtaining three eigenvalues. This matrix encodes the local curvature of the gravitational potential. Specifically, these eigenvalues determine the concavity of ϕ on the principal axes, at each point. We use these eigenvalues to interpret the tendence of mass to cluster with reference with some given threshold λ. Eigenvalues bigger than λ are interpreted as a local tendence of mass to cluster in the respective eigenaxes, and viceversa. With this characterization, clusters, sheets, fillaments and voids can be defined with the number of eigenvalues above λ. Forero et. al. found in Forero-Romero et al. (2009) that the critical value that better reproduces the correct morphological populations was $\lambda = 0.2$.

With these specifications, we could obtain mass functions for galaxies belonging to clusters, fillaments and sheets. The amount of galaxies belonging to voids was strongly affected by the mentioned mass cuts and could not produce reasonable mass functions to analyze.

4 RESULTS

4.1 Preliminaries

4.2 Mass functions comparison

Figures and tables should be placed at logical positions in the text. Don't worry about the exact layout, which will be handled by the publishers. Figures are referred to as e.g. Fig. **??**, and tables as e.g. Table **??**.

5 CONCLUSIONS

The last numbered section should briefly summarise what has been done, and describe the final conclusions which the authors draw from their work.

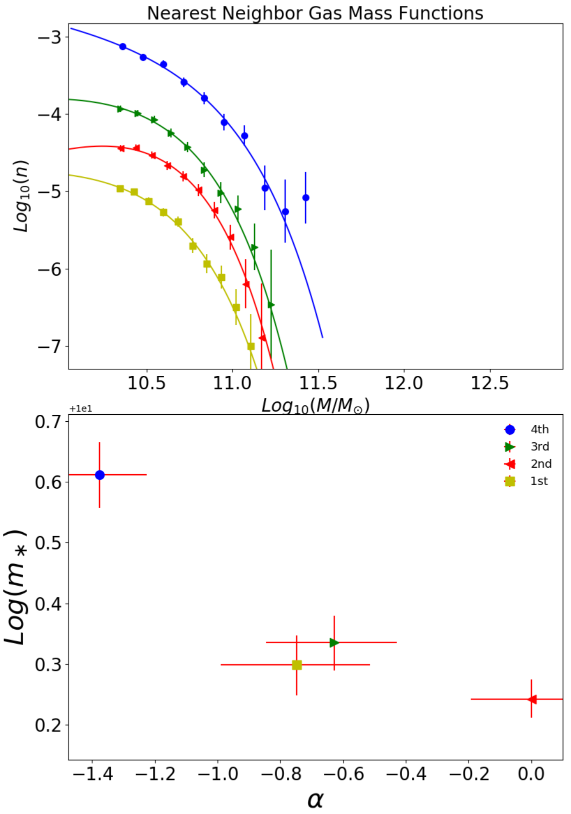

Figure 1. Upper panel: Schechter fits of each gas mass function for each environmental quartile (tendence) using the 3rd nearest neighbor definition.**Lower panel**: Knee-mass m_* and the faint end slope α values obtained from the Schechter fits for each curve shown above.

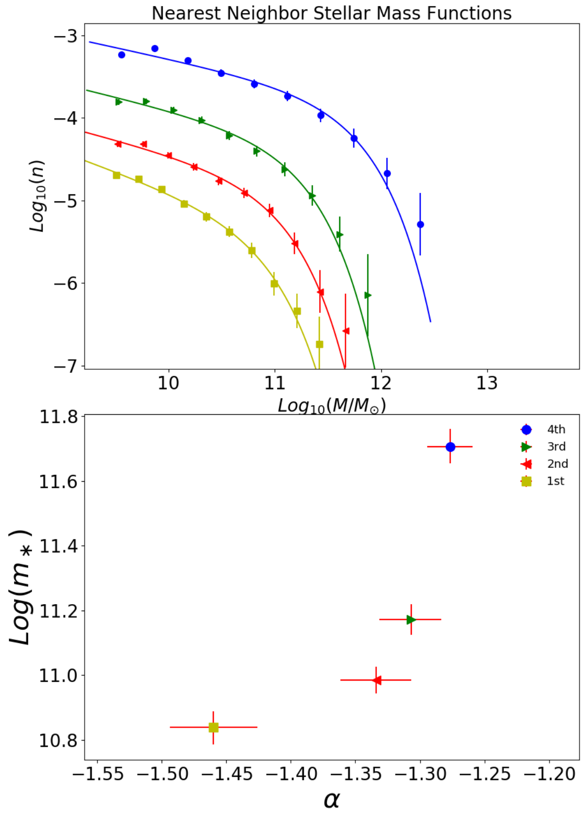

Figure 2. Similar to figure 1 using stellar mass

ACKNOWLEDGEMENTS

The Acknowledgements section is not numbered. Here you can thank helpful colleagues, acknowledge funding agencies, telescopes and facilities used etc. Try to keep it short.

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APPENDIX A: SOME EXTRA MATERIAL

This paper has been typeset from a TEX/LATEX file prepared by the author.

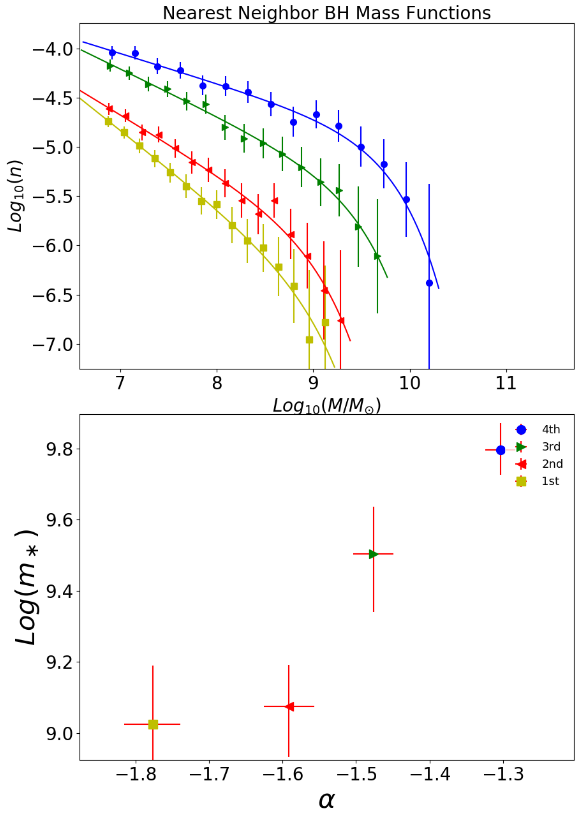

Figure 3. Similar to figure 1 using BHs mass.

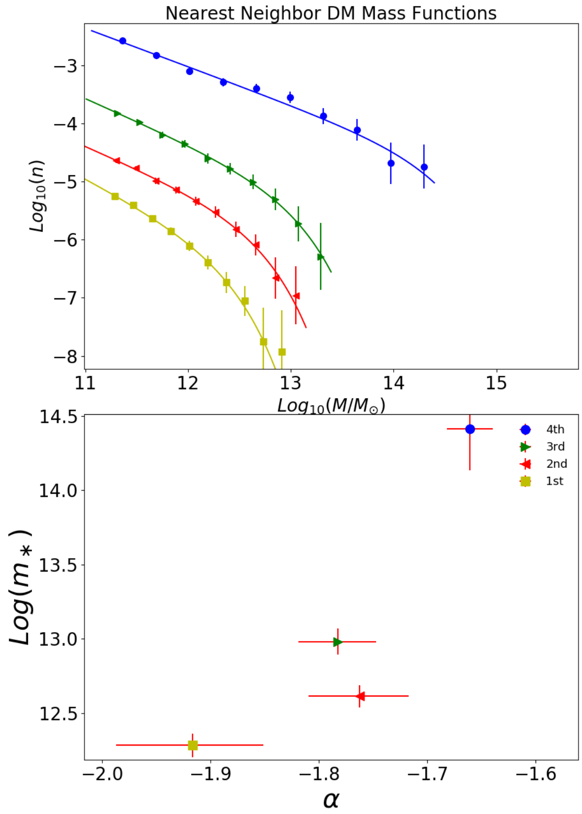

Figure 4. Similar to figure 1 using DM.

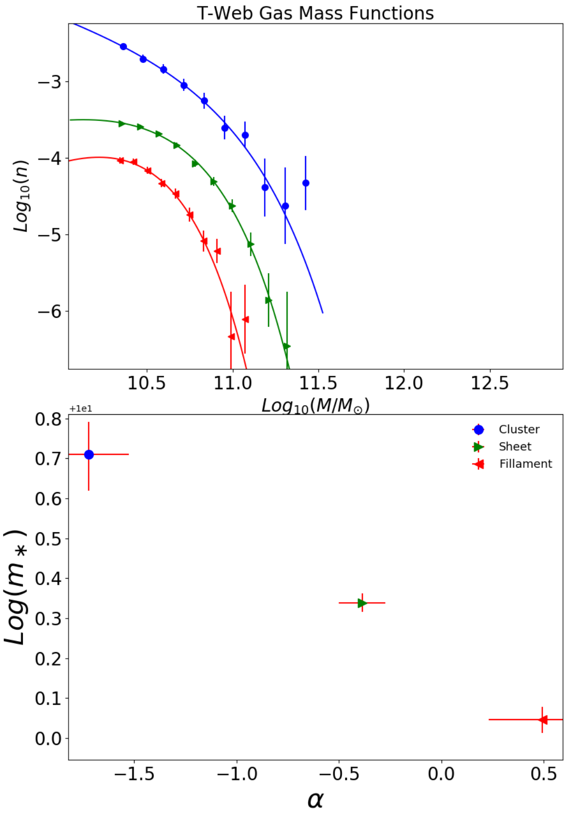

Figure 5. Upper panel: Schechter fits of each gas mass function for each morphological environment characterized by the T-Web algorithm proposed by Forero et al.**Lower panel**: Knee-mass m_* and the faint end slope α values obtained from the Schechter fits for each curve shown above.

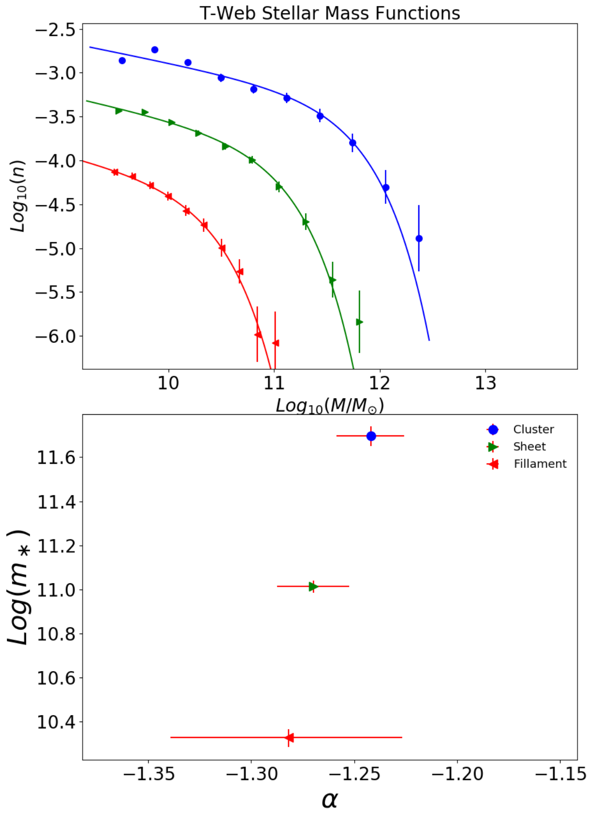

Figure 6. Similar to figure 5 using stellar mass

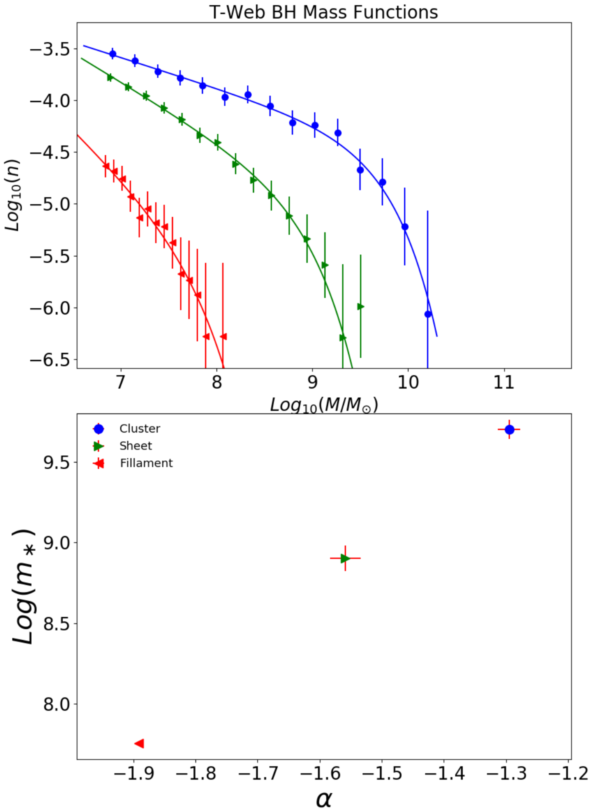

Figure 7. Similar to figure 5 using BHs mass.

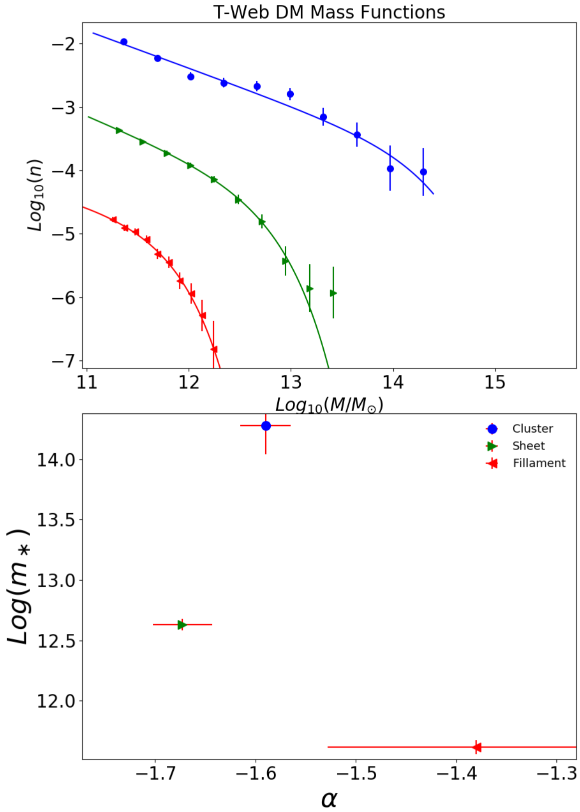

Figure 8. Similar to figure 5 using DM.