The ALHAMBRA Survey: galaxy distribution at the smallest scales.

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Motivation

The Halo Occupation Distribution (HOD) is a powerful framework to study the complex relation between the spatial distribution of galaxies and the dark matter distribution in the haloes that host them. It determines the probability that a halo of viral mass M contains N galaxies, and their relative spatial and velocity distributions, but it has been shown that some of its standard assumptions might not be entirely correct. One of them is that satellite galaxies trace the underlying dark matter distribution of haloes. However, some studies [1, 2] have shown variations between the density profile of galaxies and the Navarro-Frenk-White (NFW) profile of dark matter [3], suggesting the presence of a spatial bias. We measure the galaxy clustering at small scales in the photometrical survey ALHAMBRA to study the satellite galaxy distribution. We apply a Generalized NFW (GNFW) profile for the galaxies and use the MCMC method to fit the HOD and density parameters.

The ALHAMBRA survey

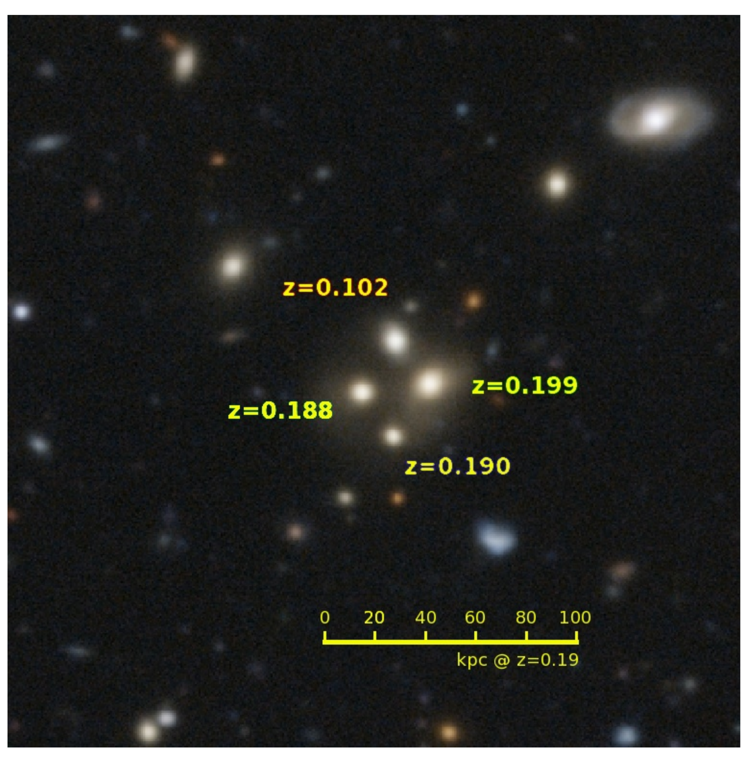


Figure 1: A small patch of the sky in the ALHAMBRA survey.

Accurate photometric redshift. The survey's multi-filter system covers the entire optical range with 20 contiguous, medium-band filters, and the near infrared with the three standard broad-band filters J, H and K_s. This is a wide coverage that allows for a deep reach and a reliable photometric redshift determination ($\sigma_z \lesssim 0.014(1+z)$ for $I < 24.5$) [4].

Small scales. The deep reach of ALHAMBRA allows to study the clustering of faint galaxies with an accurate redshift. Figure 1 shows the photometric redshift of galaxies with a separation perpendicular to the line of sight lower than 0.03 h^{-1} Mpc, deep in the small scales regime.

Sample selection. Our catalogue covers an effective area $A_{\rm eff} = 2.46\,{\rm deg}^2$ down to $I = 23$. We performed the selection of 18 galaxy samples, which are marked in green in Figure 2.

- Redshift bins centered in $z = 0.3$, $z = 0.5$, $z = 0.7$ and $z = 0.9$.
- Stellar mass M_s thresholds between $10^{9.5}$ and 10^{11} $h^{-1}M_\odot$.

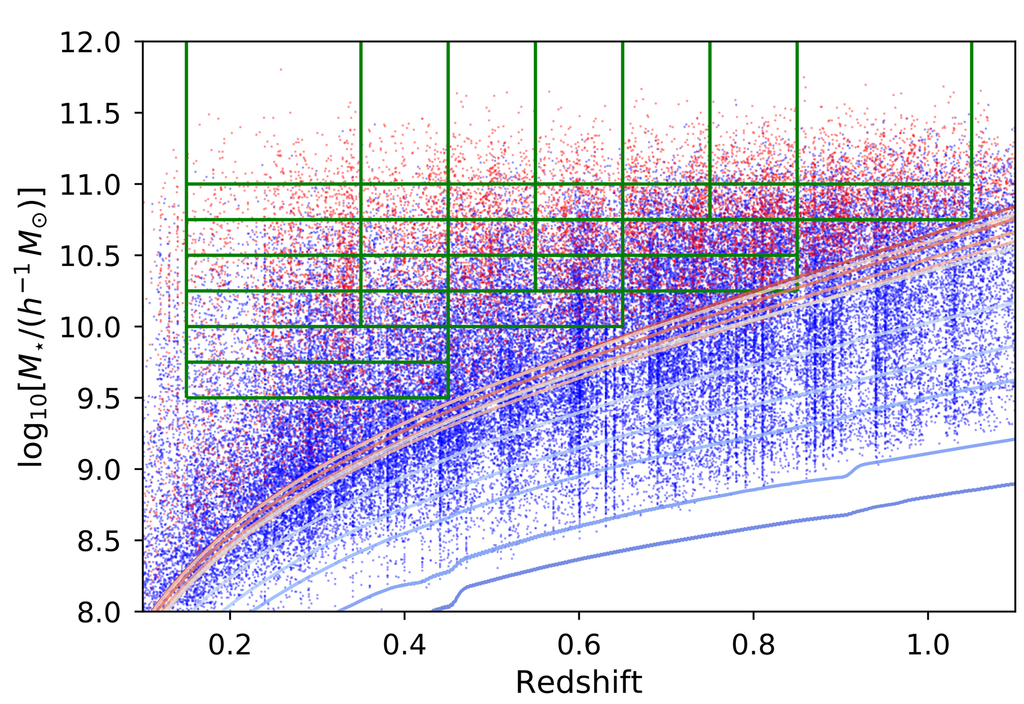


Figure 2: Sstellar mass vs. redshift. The red and blue dots correspond to quiescent and star-forming galaxies.

HOD modeling and methods

HOD model [5]

$$\langle N_C(M)\rangle = \begin{cases} 1 & \text{if } M > M_{min} \\ 0 & \text{if } M \le M_{min} \end{cases}$$

$$\langle N_S(M)\rangle = \langle N_C(M)\rangle \cdot \left(\frac{M}{M_1}\right)^\alpha$$

- M_{min}: minimum halo mass required to host a central galaxy
- M_1: halo mass at which, on average, there is one satellite galaxy in the halo

GNFW density profile

$$\rho(r|M) = \frac{\rho_s}{(r/r_s)^\gamma\,(1+r/r_s)^{3-\gamma}}$$

$$c_g = f_g \times c_{DM} \qquad c \equiv r_{\rm vir}/r_s$$

- γ: inner slope of the density profile
- f_g: concentration parameter
- c_g and c_{DM}: concentrations of galaxies and dark matter
- NFW profile of dark matter: $\gamma = 1$, $f_g = 1$

Galaxy clustering. We measure the projected correlation function $w_p(r_p)$ with the python library `corrfunc`. We also estimate the number density of galaxies $n(z)$.

Fitting the parameters. We fit M_{min}, M_1, α and f_g, and keep γ fixed to 1. We define the model with `halomod` and run an MCMC sampling with `emcee`, using $w_p(r_p)$ and $n(z)$.

References

[1] Watson D. F., Berlind A. A., McBride C. K., Hogg D. W.,Jiang T., 2012, ApJ, 749, 83
[2] McDonough B., Brainerd T. G., 2022, The Astrophysical Journal, 933, 161
[3] Navarro J. F., Frenk C. S., White S. D. M., 1997, ApJ, 490, 493
[4] Molino A. et al., 2014, MNRAS, 441, 2891
[5] Zehavi I. et al., 2005, The Astrophysical Journal, 630, 1

Do satellite galaxies trace dark matter?

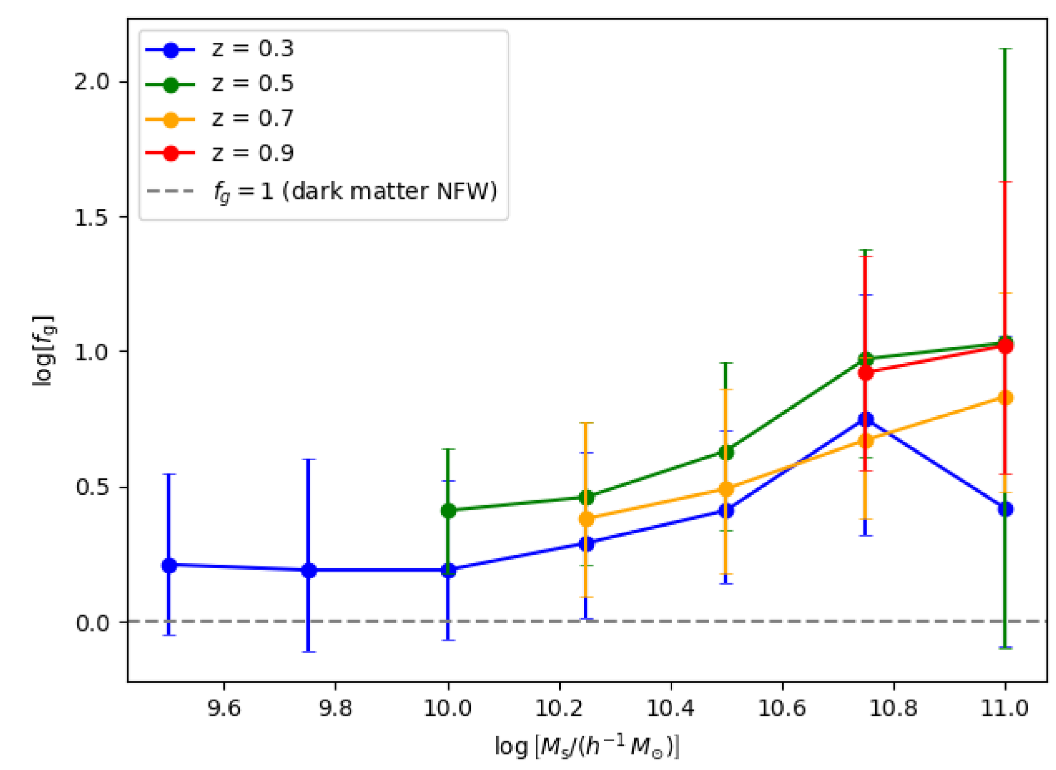
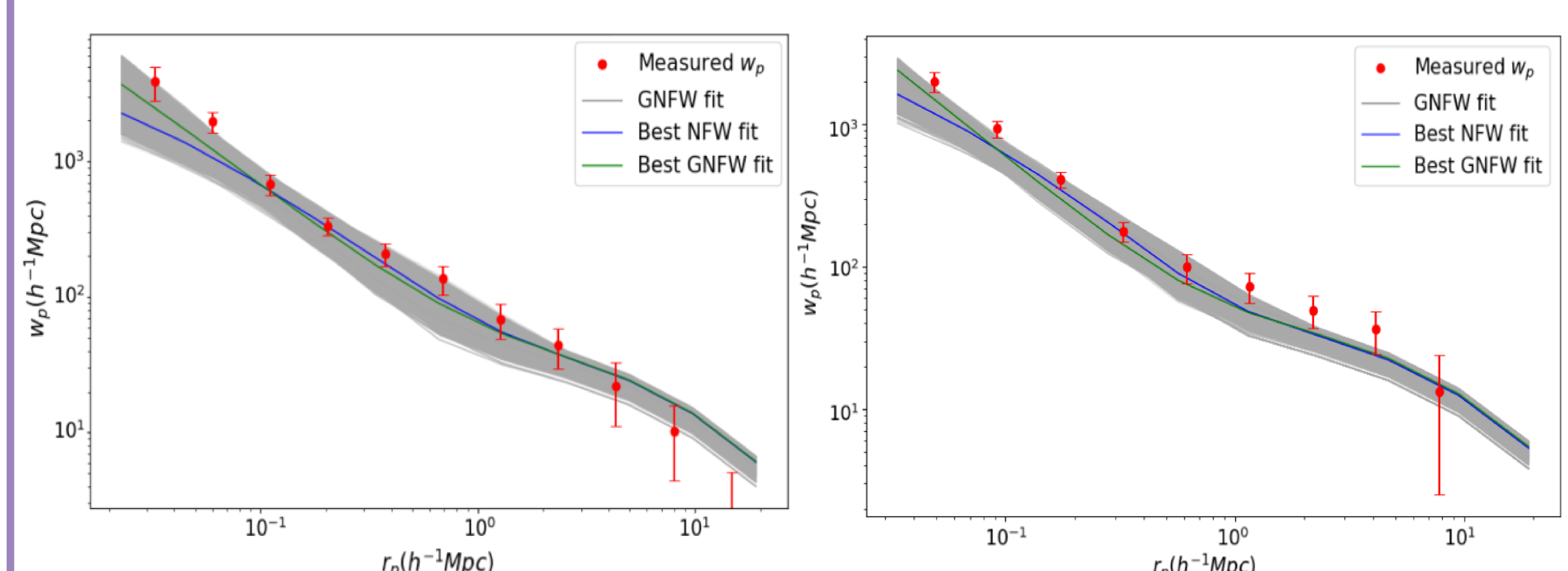


Figure 3: Results of the parameter f_g for all samples. The error bars are the 68% CI.

Results of f_g. The concentration parameter takes a value between $1.5 < f_g < 11$ for all samples.

Dependence on M_s. The concentration of galaxies is higher for samples with higher stellar mass.



(a) $z = 0.5$, $M_s = 10^{10.75}$ $h^{-1}M_\odot$ (b) $z = 0.9$, $M_s = 10^{10.75}$ $h^{-1}M_\odot$

Figure 4: Projected correlation function measured from the data (red) and modeled by the GNFW profile (grey). The blue and green lines are the NFW and GNFW best fits.

Deviations from NFW. At small scales, the measured projected correlation function is steeper than the predictions from the NFW profile. The deviations are bigger on higher stellar mass samples, but these samples are also harder to converge, either due to a higher complexity of the model or low statistics.

GNFW model. The MCMC fitting with the GNFW density profile adjusts better to these deviations, even if it is still less steep than the measurements.

Final remarks and Work in progress

Results. We have obtained an $f_g > 1$ for all samples, which suggests a steeper density profile for satellite galaxies than that for the dark matter. This would imply the presence of a spatial bias affecting satellites at small scales.

Future improvements. Results on the correlation function modeled with a varying f_g are still not steep enough and insufficient to accurately predict the galaxy distribution. This might be caused by the lack of constraining power of f_g on its own. Introducing a varying γ could help to improve the predictions.

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