Halo-Galaxy Connection: HOD and Clustering in TNG300

Analyzing Clustering Differences with HOD Models and Correlation Function

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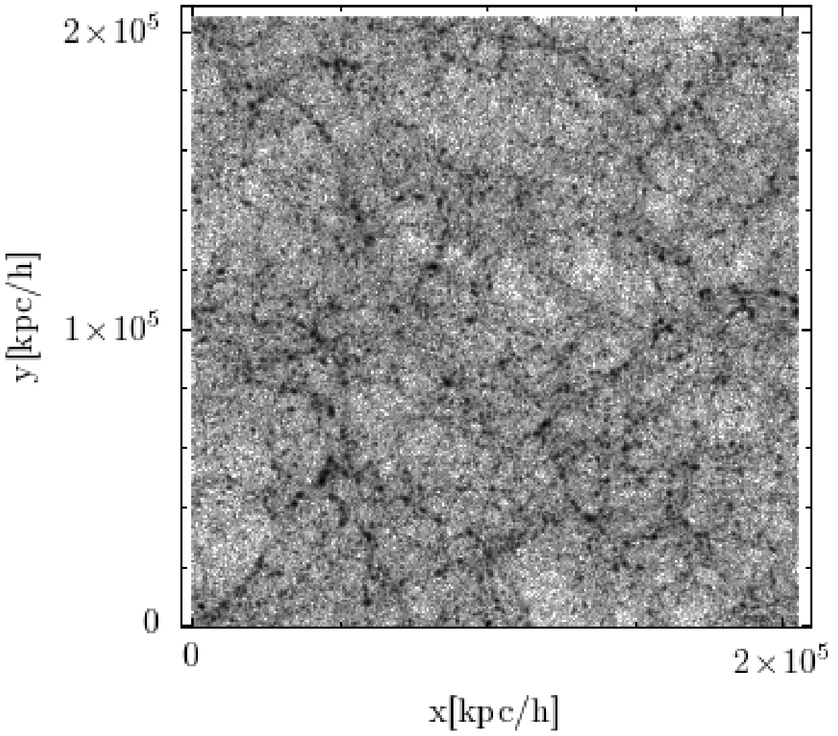
Theoretical Framework

Motivation: Why is it important to study the halo-galaxy connection and the correlation function?

- Distribution of dark matter $\longrightarrow$ Distribution of galaxies
- Allows to trace how the structures of the universe evolved from the Big Bang to the present.
- HOD is used to populate dark matter halos with galaxies in cosmological simulations.



Theoretical Framework

- HOD:

$$P(N_c|M) \equiv \text{Probability density function for centrals}$$
$$P(N_s|M) \equiv \text{Probability density function for satellites}$$
$$u_s(r|M), u_c(r|M) \equiv \text{Radial number density of satellites, centrals}$$

$$\langle N_c \rangle_M = \sum_{N_c=0}^{1} N_c P(N_c|M) = P(N_c = 1|M) \tag{1}$$

$$u_c(r|M) = \delta^D(r) \tag{2}$$

$$\langle N_s \rangle_M = \sum_{N_s=0}^{\infty} N_s P(N_s|M) \tag{3}$$

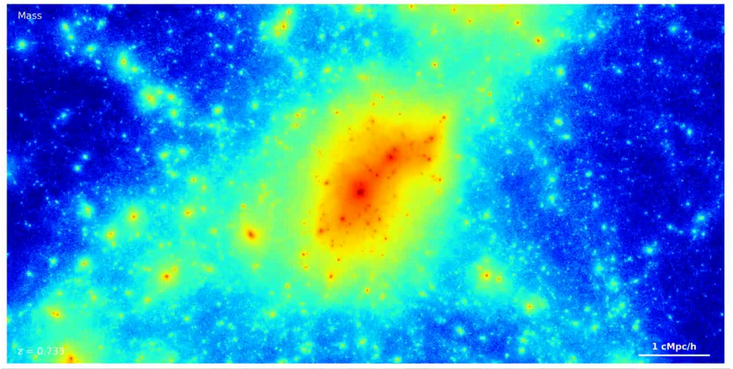
- 2pCF:

$$w_p(r_p) = \int_{-\infty}^{\infty} \xi(r_p, r_\pi) dr_\pi$$

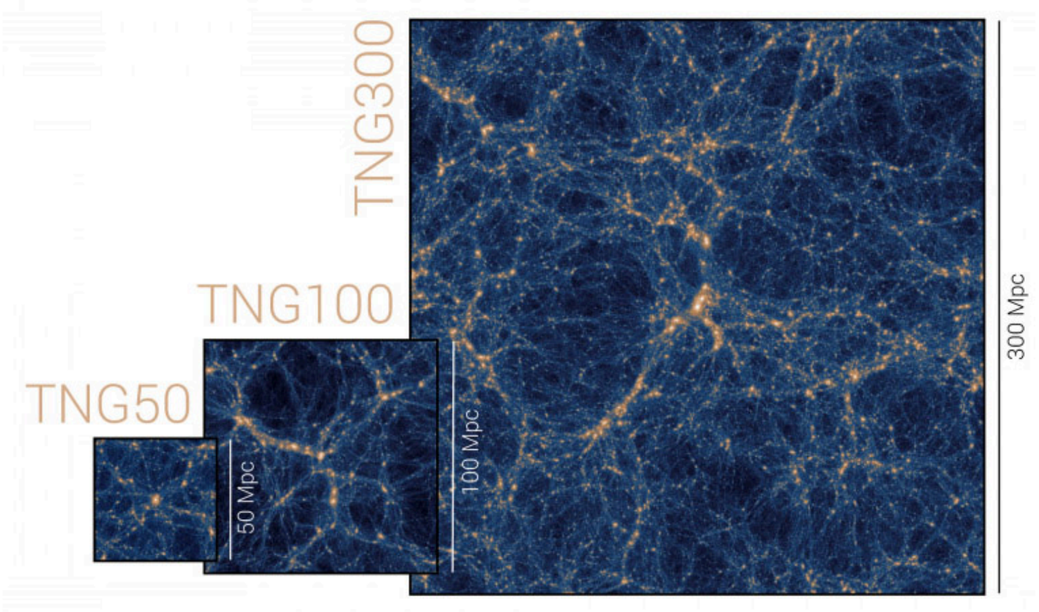
Data

- **TNG300-1**
  Planck2015
  Ωm = 0.3089
  ΩΛ = 0.6911
  Ωb = 0.0486
  h = 0.6774

Snapshot 99:
Redshift (z): 0.00
Edad del universo: 13.803 Gyr
Lookback time: 0.000 Gyr



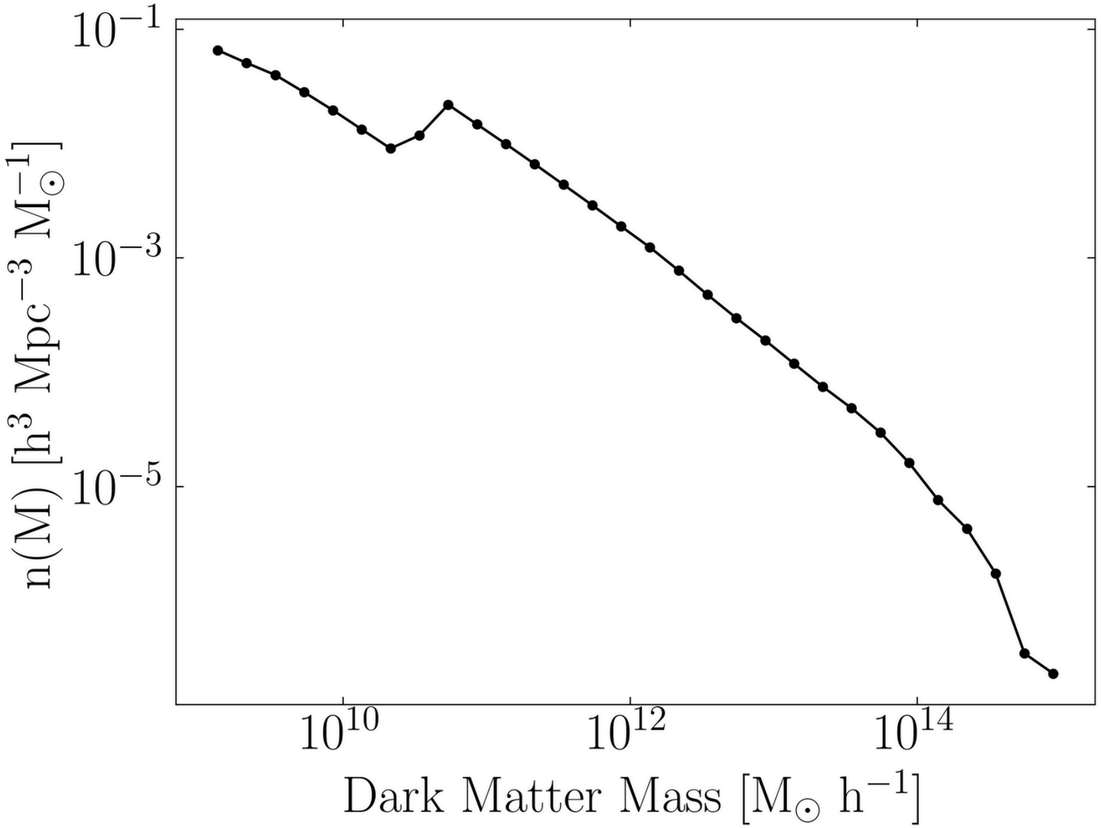
This snapshot allows the analysis of the formation and distribution of mature galaxies, enabling the study of the structure of the universe in the present.



Methods

Selection of Data Used

- Dark Matter Halos with Dark Matter Mass > 10^9 (86.24%)



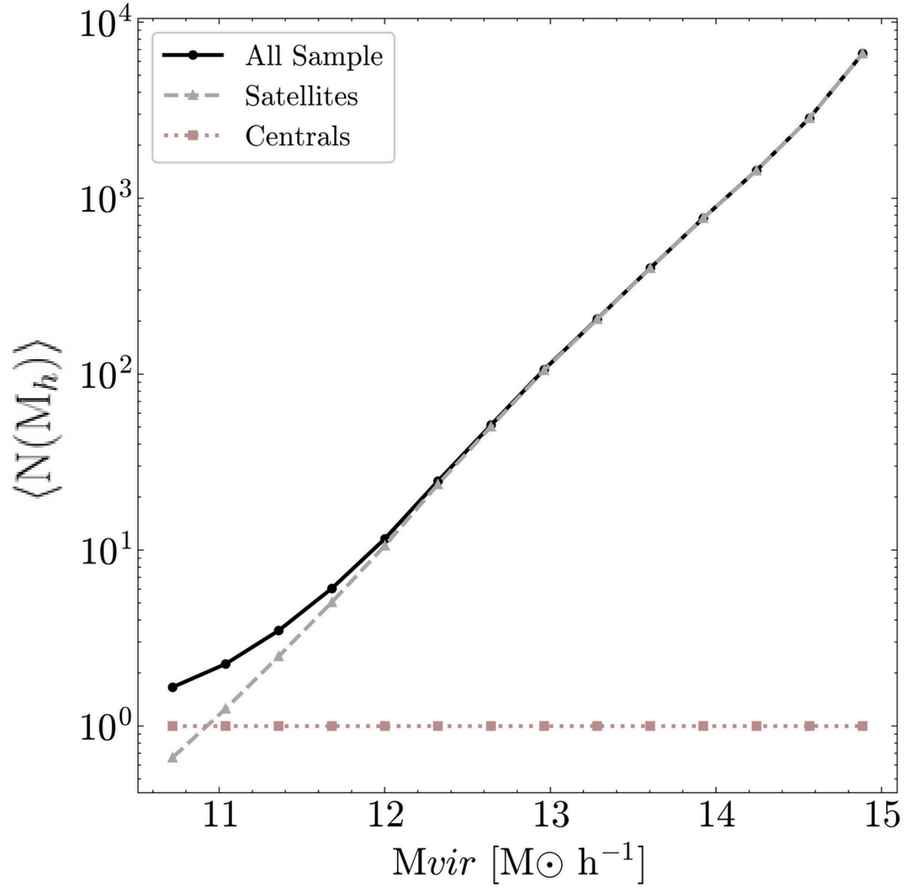
Results

Thresholds for Sample Selecction: Stellar Mass

- If we assume that:
  - There isn´t DM satellite subhalos without a central DM halo
  - All DM subhalos contains galaxies
  - All DM host halos have at least one galaxy (i.e central subhalo).

Thresholds for Sample Selecction: Stellar Mass

- HOD considering that all subhalos have galaxies

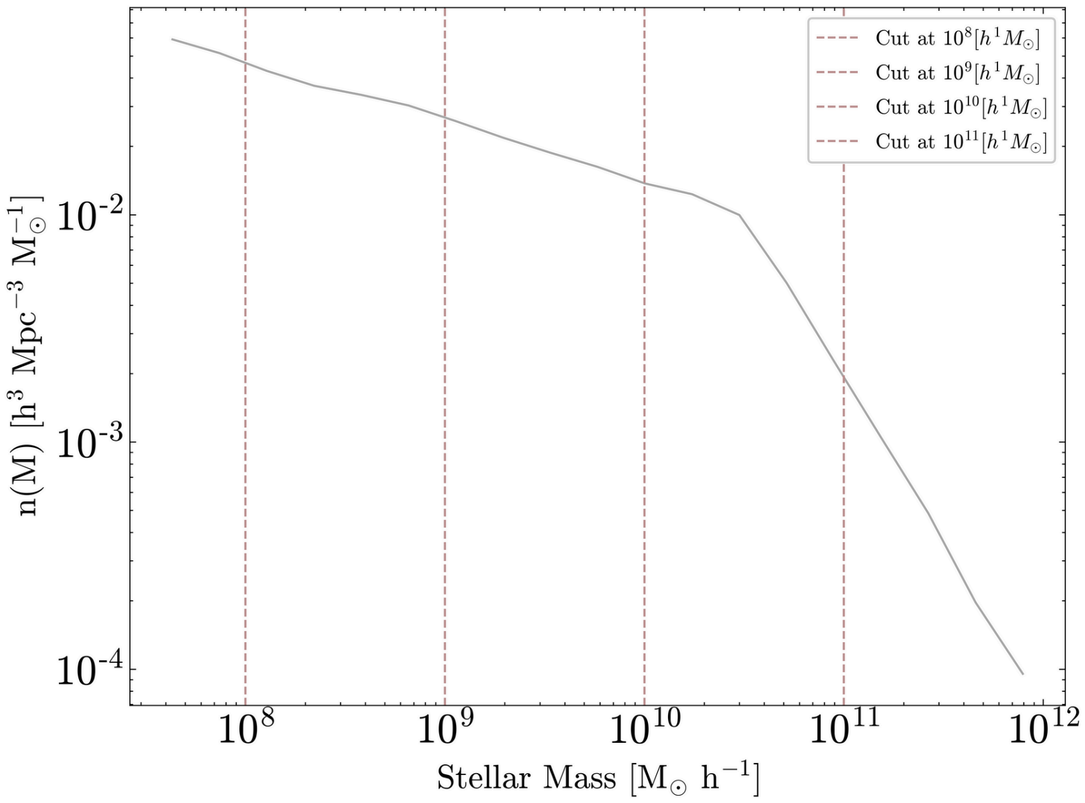


- For centrals is always 1
- We have halos without satellites, but not in the way we expected

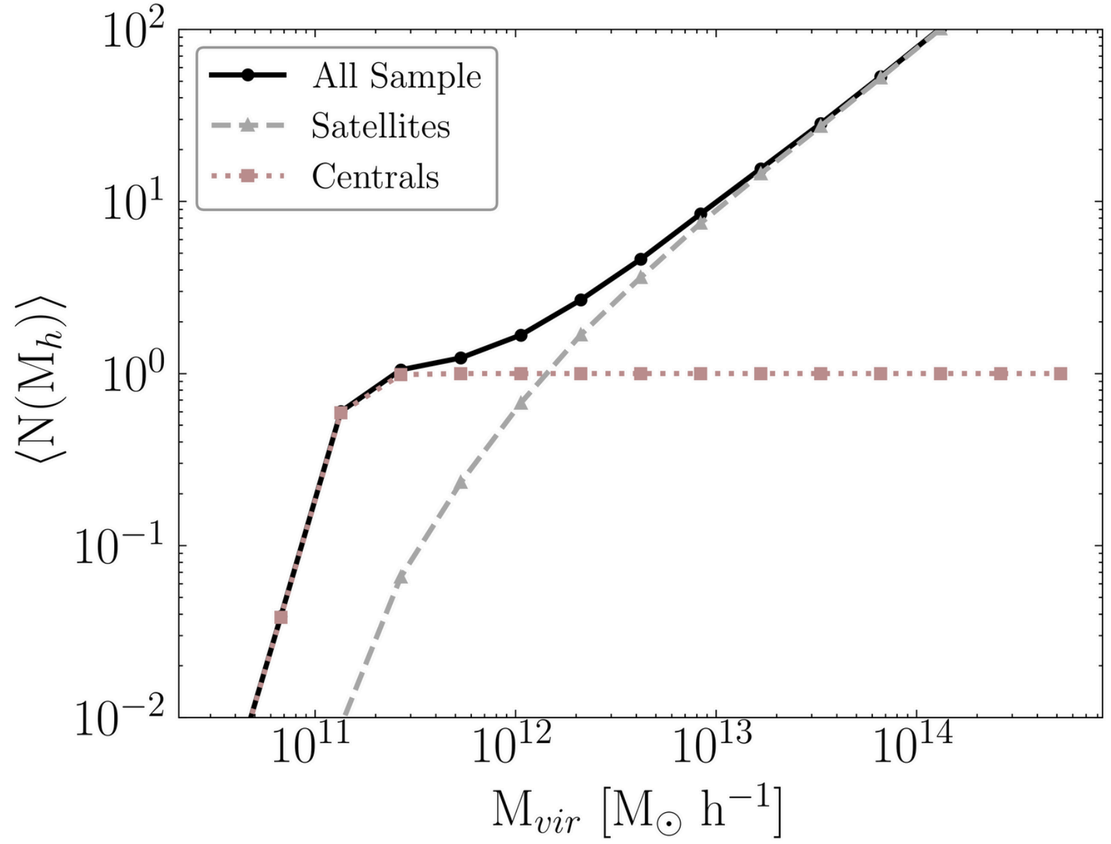
Thresholds for Sample Selecction: Stellar Mass

- Now, setting a threshold for stellar mass

- Mass Function with the cuts we use

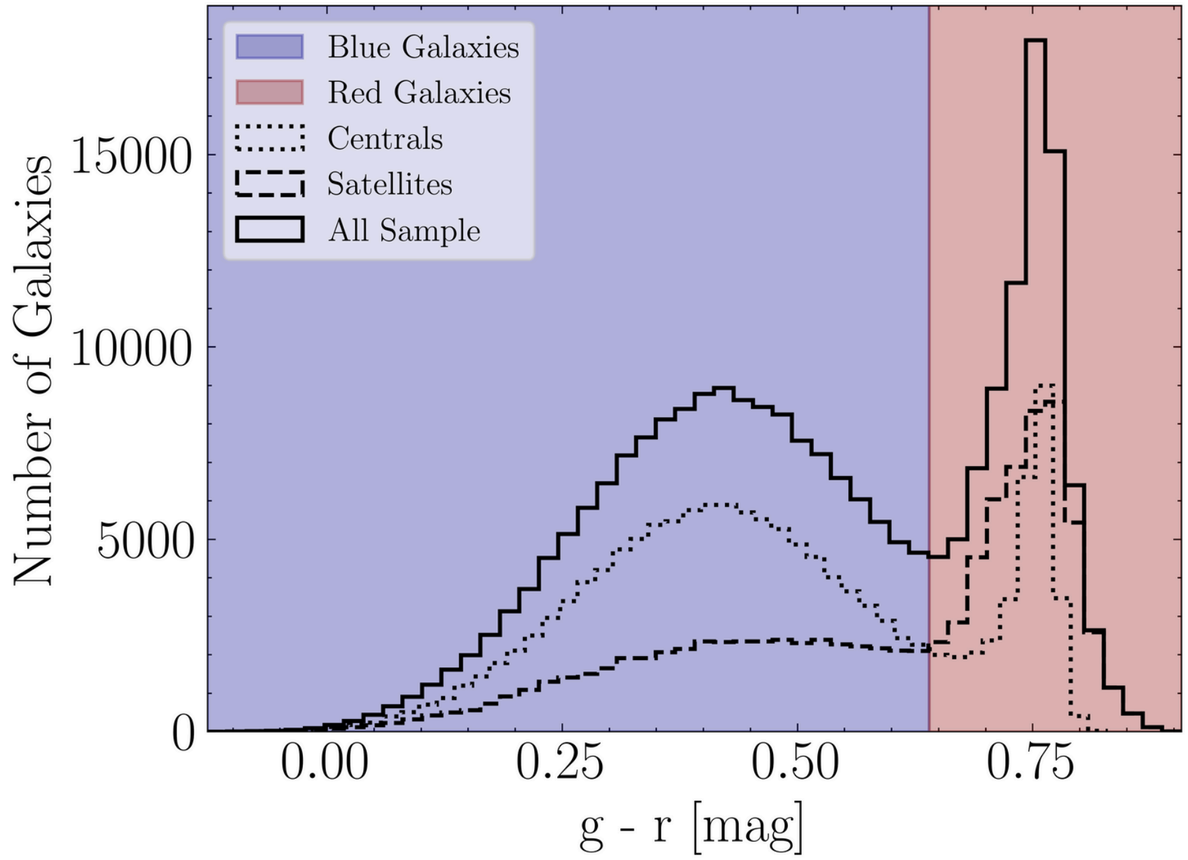


- HOD for threshold in Stellar Mass > 10^9



Thresholds for Sample Selecction: Color (Red & Blue)

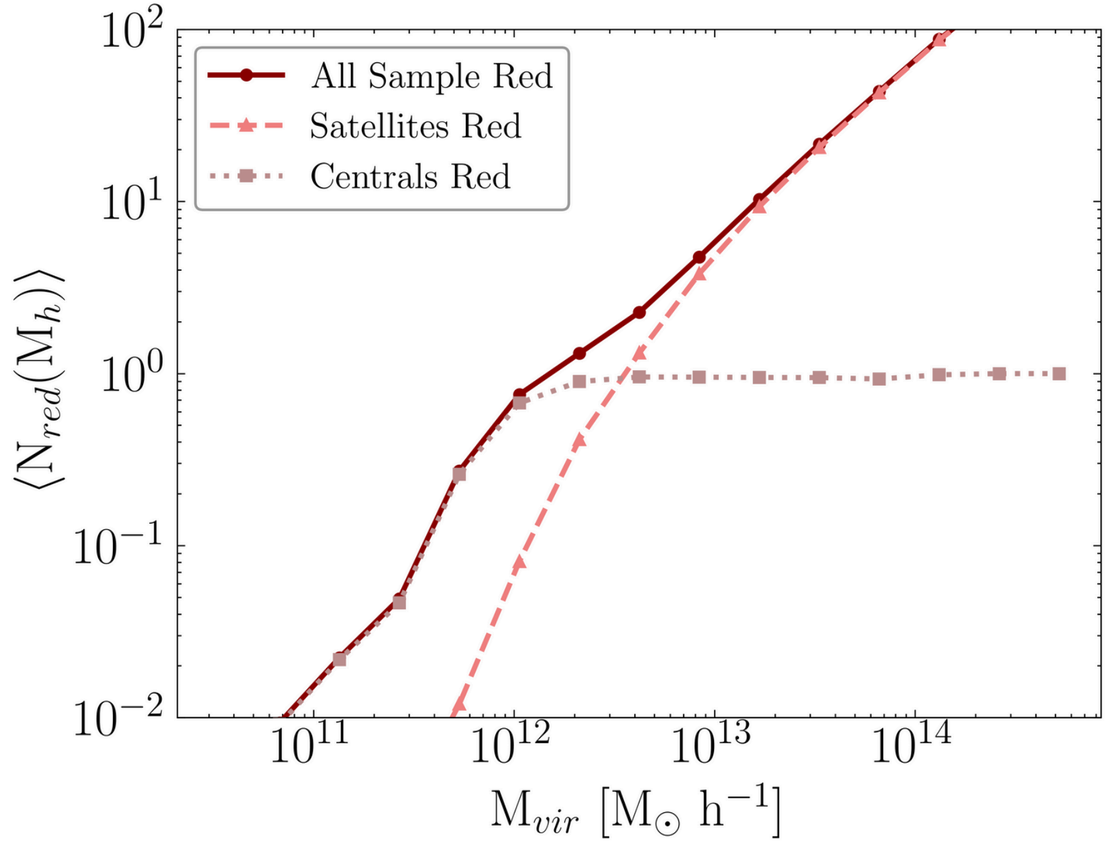
- Galaxies with g-r < 0.64 [Mag][1] are Blue & with g-r > 0.64 [Mag][1] are Red



[1] Dylan Nelson et al. (2018) determine that the threshold is aprox. at g-r = 0.6

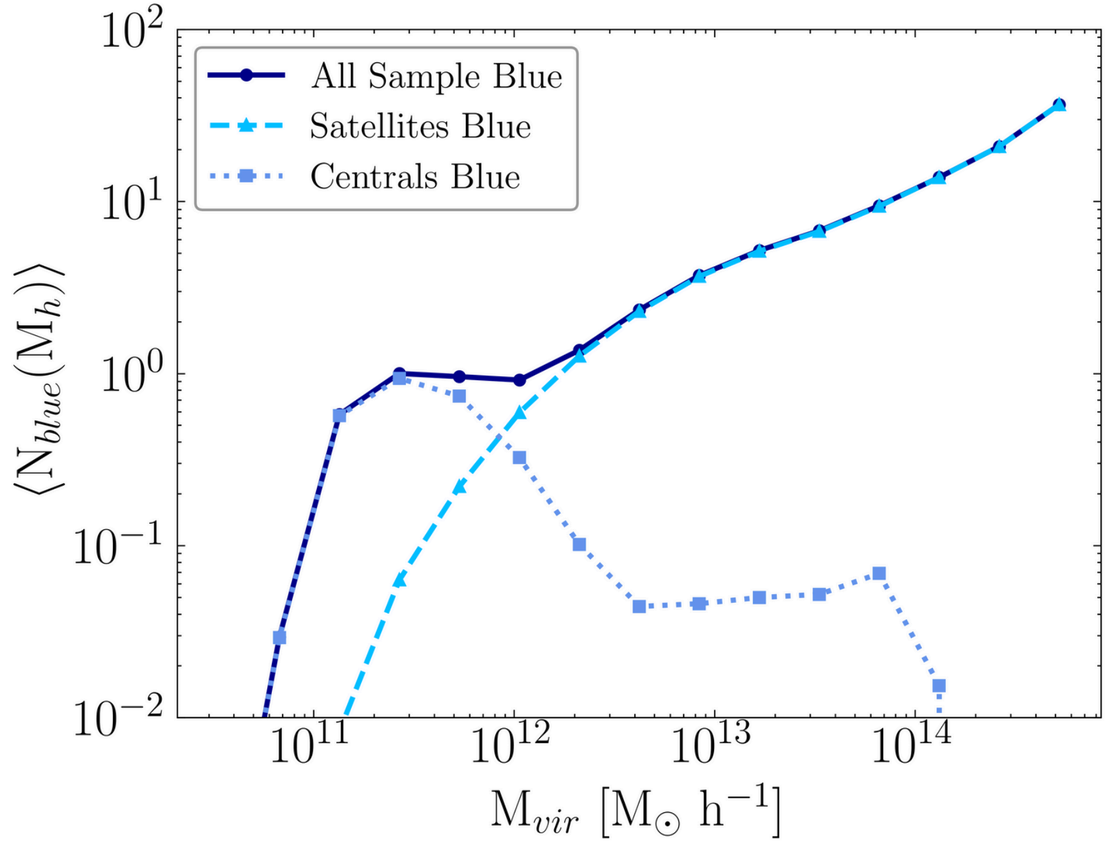
Thresholds for Sample Selecction: Color (Red & Blue)

- HOD for red galaxies (g-r > 0.64 [Mag])



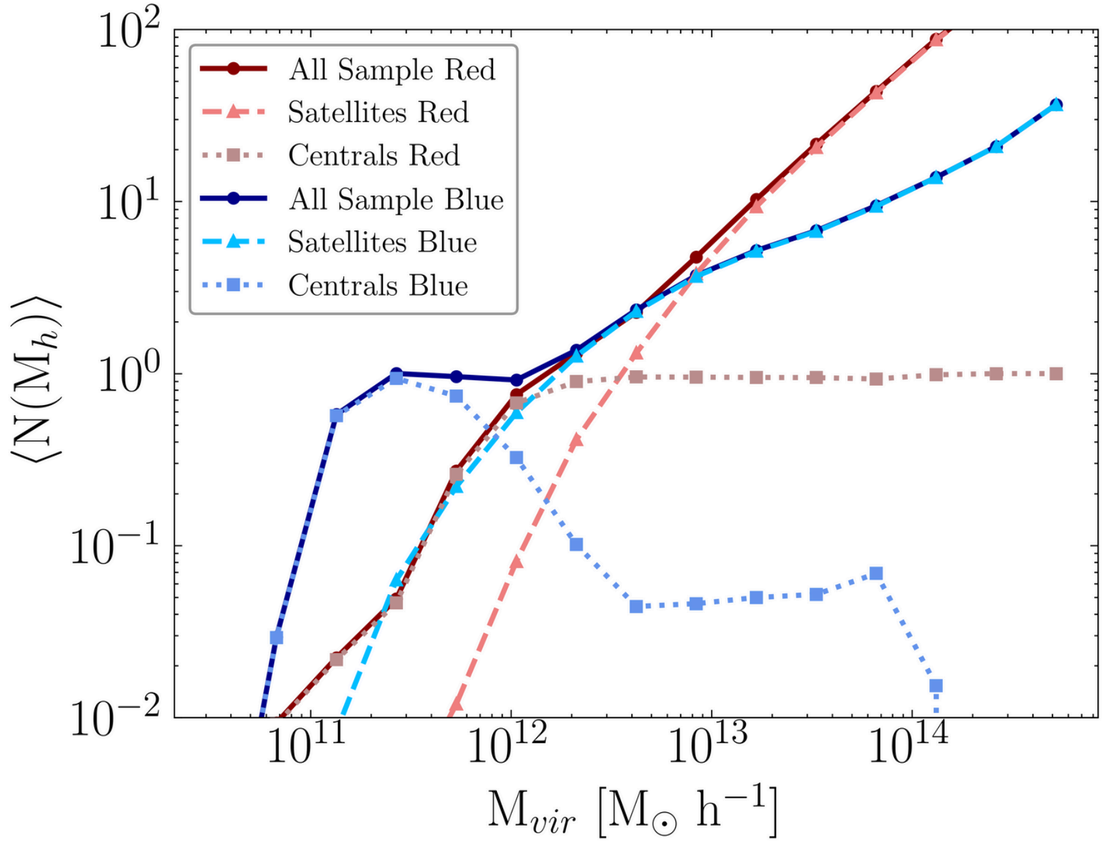
Thresholds for Sample Selecction: Color (Red & Blue)

- HOD for blue galaxies (g-r > 0.64 [Mag])



Thresholds for Sample Selecction: Color (Red & Blue)

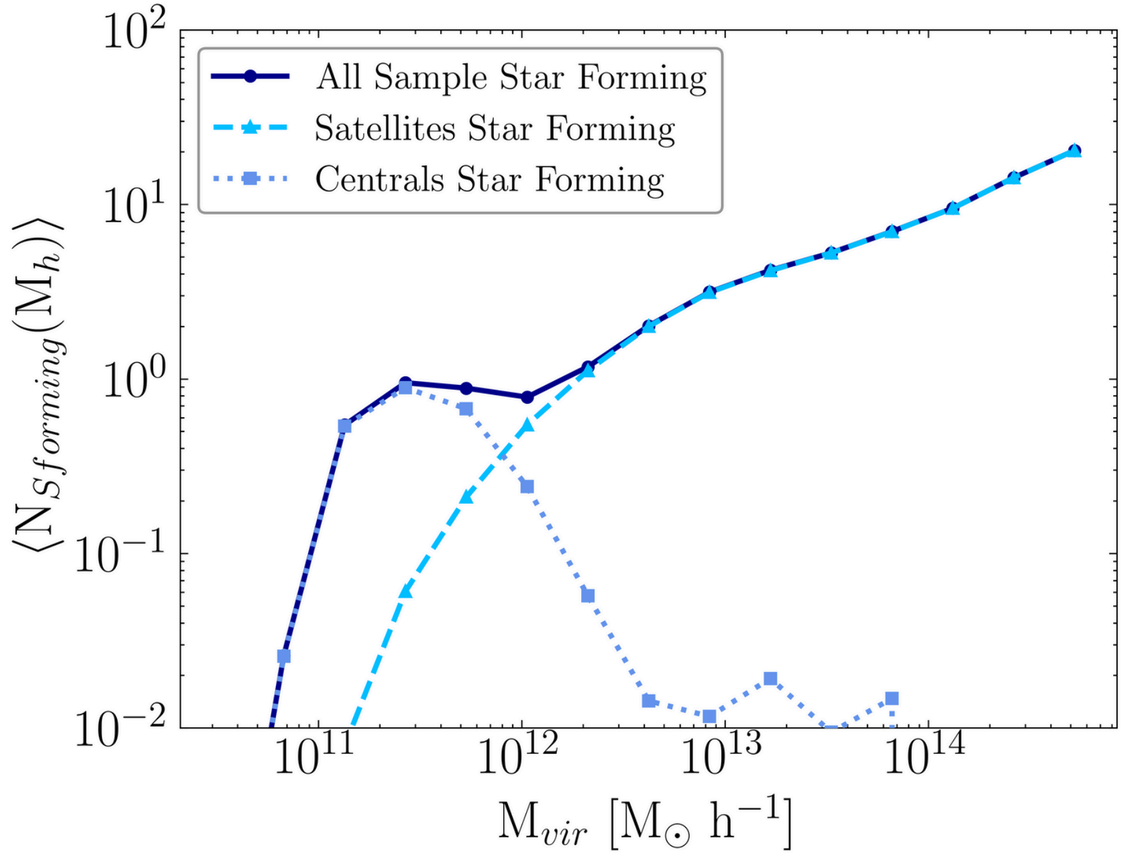
- HOD for all toghether



Thresholds for Sample Selecction: SFR (Star forming & Quiescentes)

- Galaxies with sSFR > 10^(-10.5) [1/yr] are Star Forming

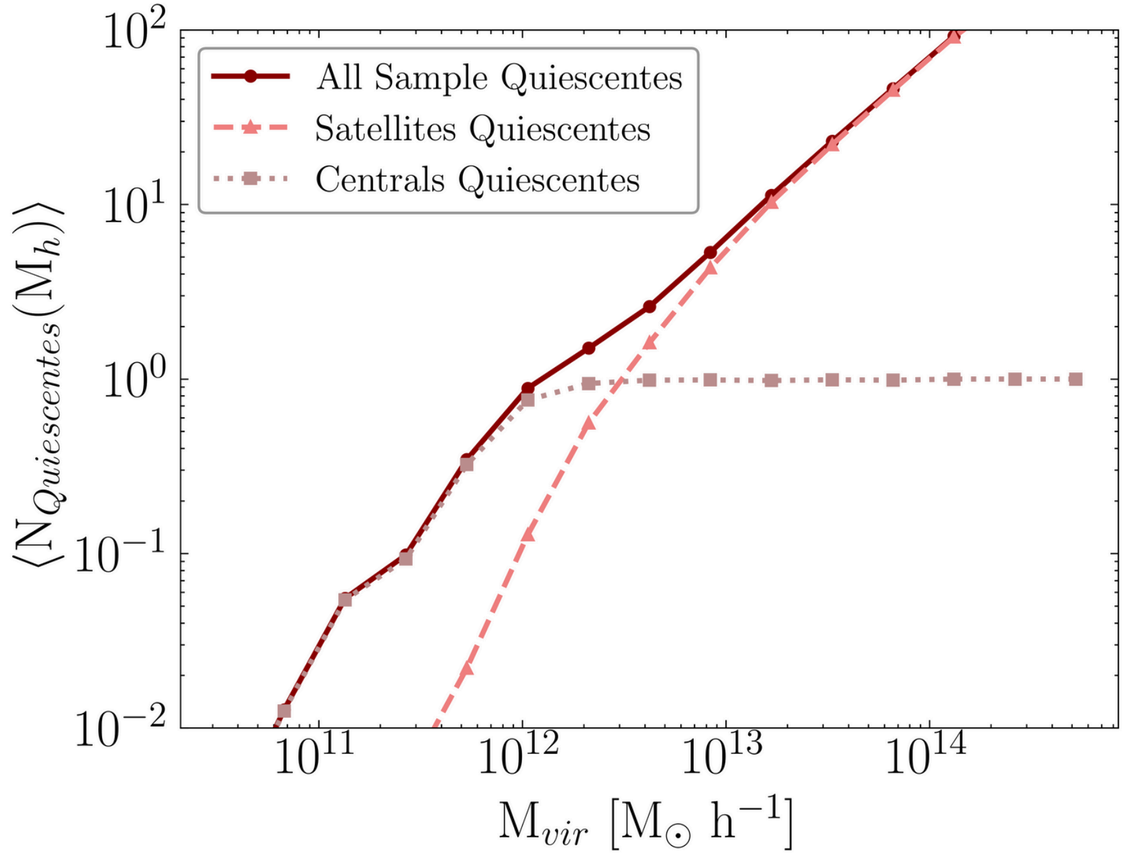
1. HOD for Star Forming Galaxies:



Thresholds for Sample Selecction: SFR (Star forming & Quiescentes)

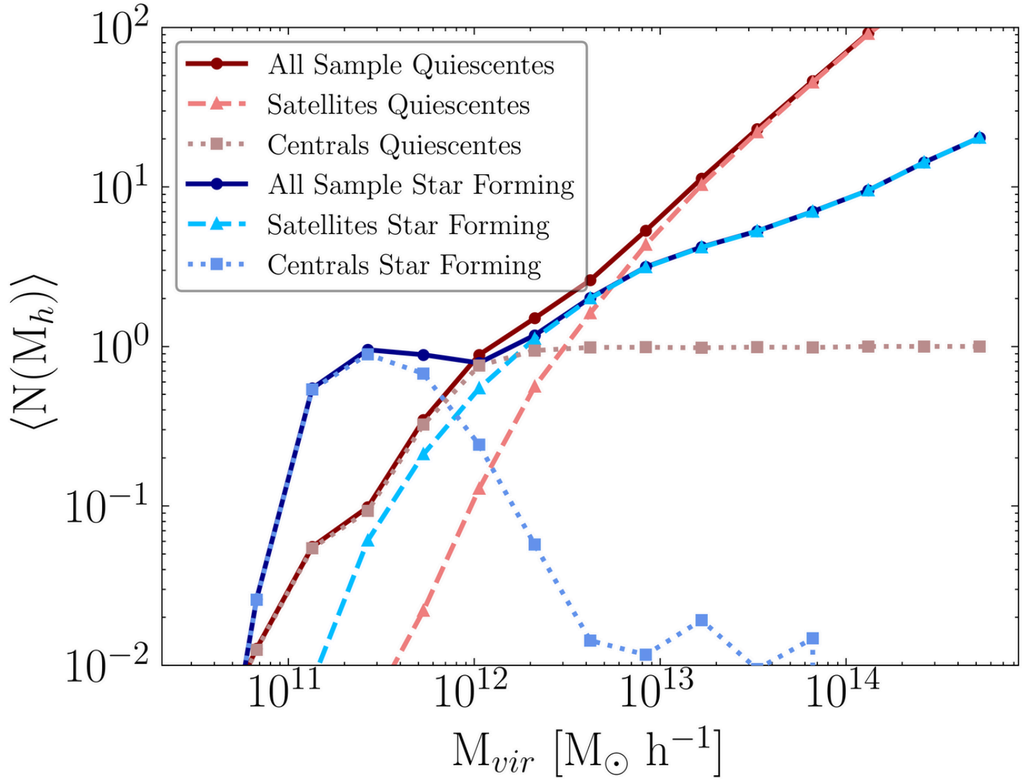
- Galaxies with sSFR < 10^(-10.5) [1/yr] are Quiescentes

2. HOD for Quiescentes Galaxies:



Thresholds for Sample Selecction: SFR (Star forming & Quiescentes)

- HOD for all toghether



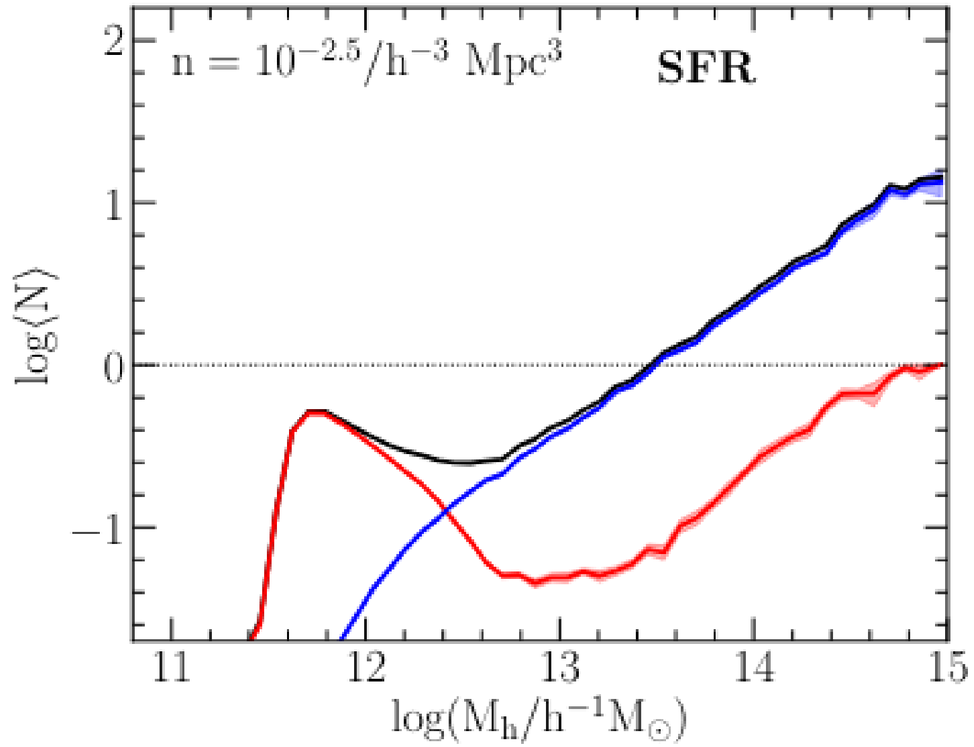
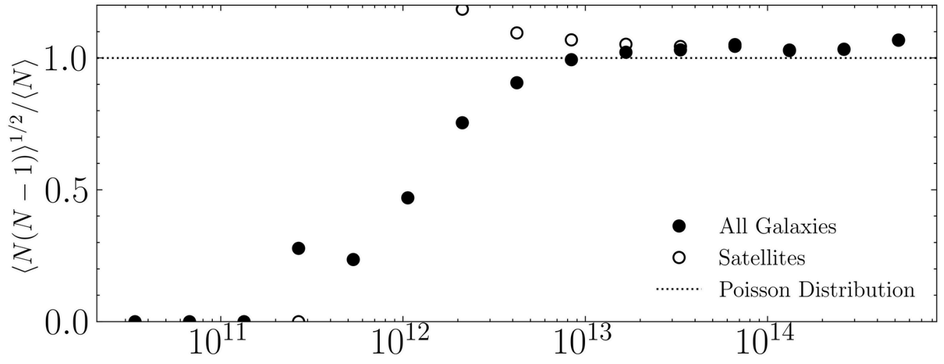
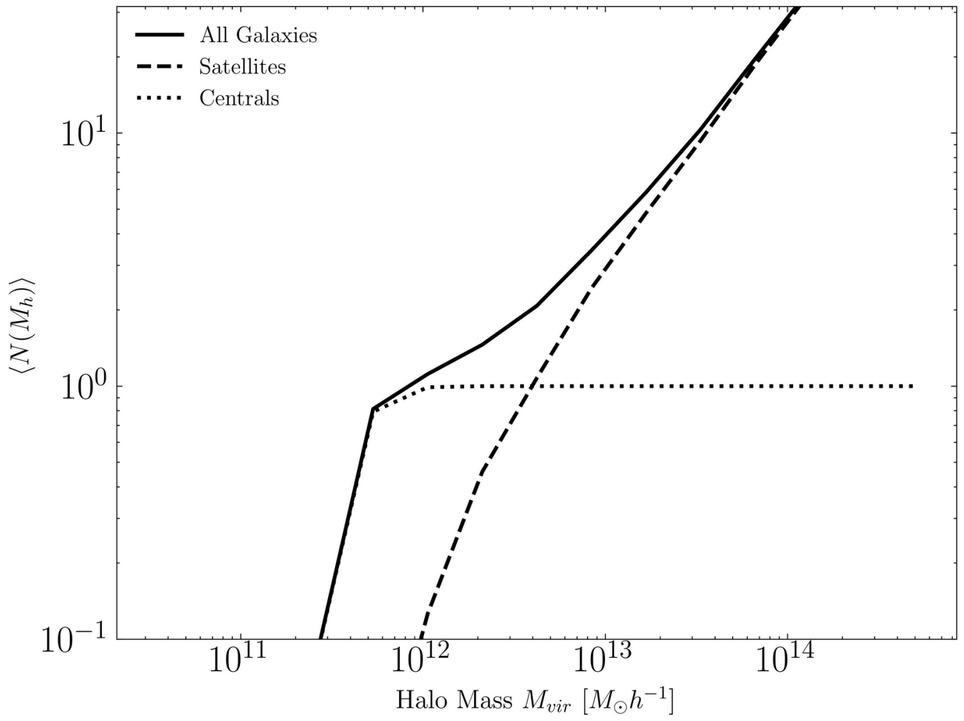


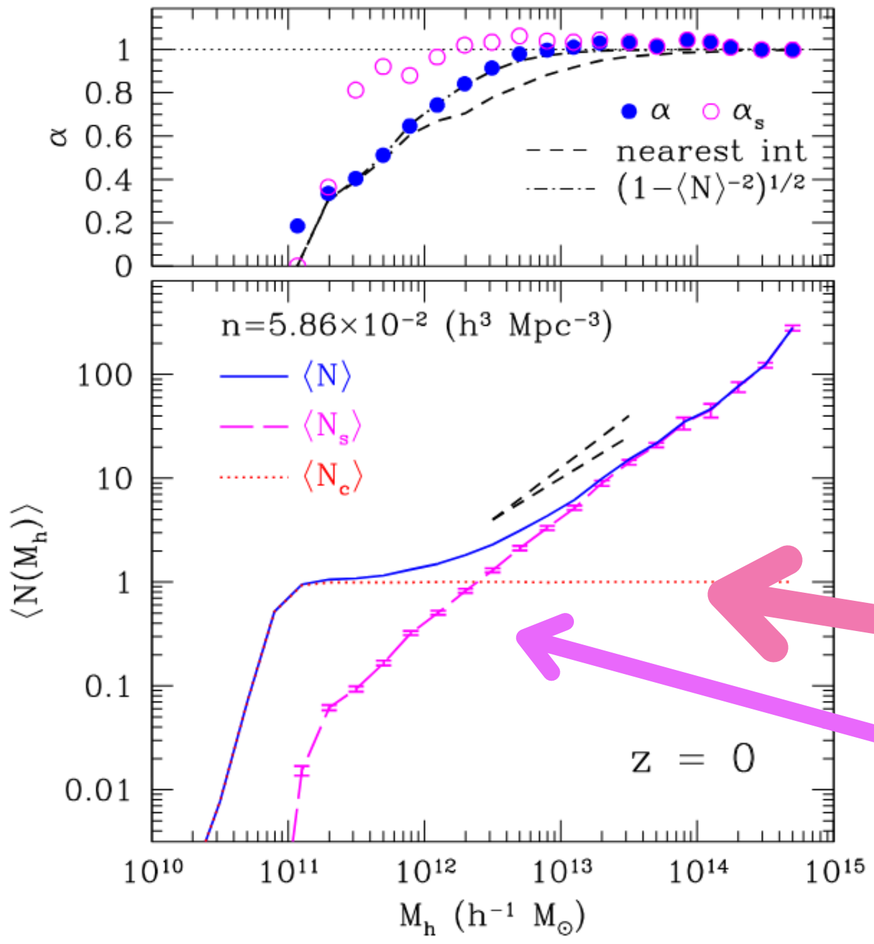
Figure: Blue line (Satellites) , red line (Centrals)

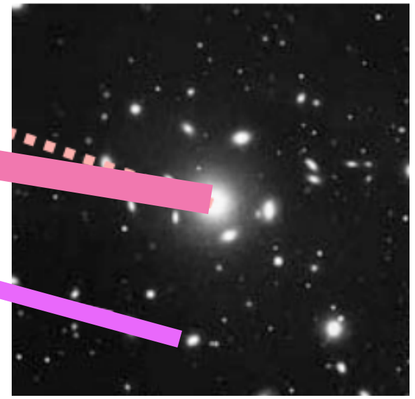
Esteban Jiménez, Sergio Contreras et al.

Mean Occupation Number and Scatter for Centrals and Satellites as a Function of Halo Mass









Kauffmann et al. 2001; Cooray 2002;
Kravtsov et al. 2003

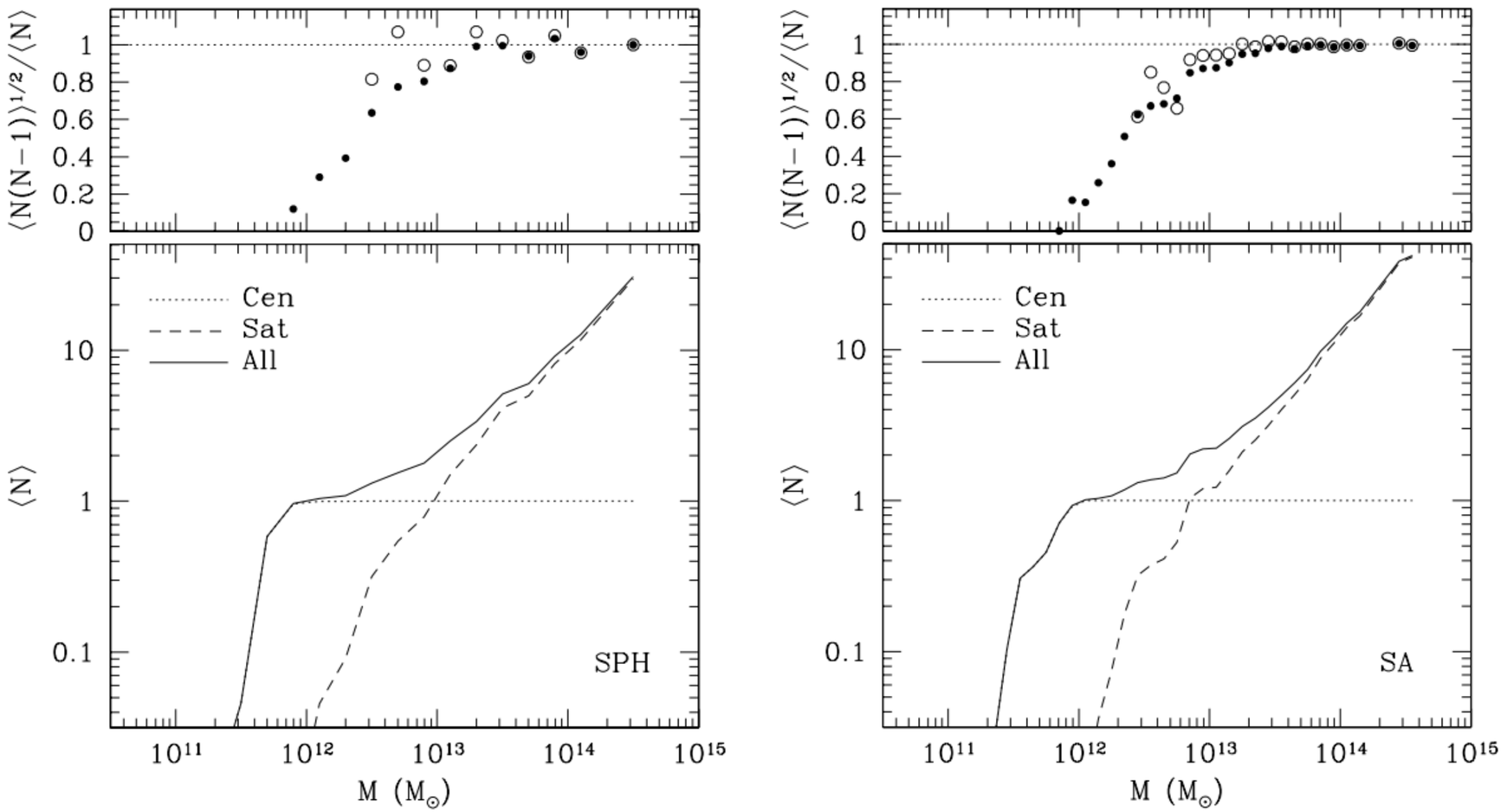


FIG. 1.—Mean occupation number and scatter as a function of halo mass, separated into central and satellite galaxies. Predictions are shown for the $\bar{n}_g = 0.02\ h^3\ \mathrm{Mpc}^{-3}$ samples from the SPH simulation (*left*) and from the SA model (*right*). The bottom panels plot the mean occupation numbers of central, satellite, and all galaxies. In the top panels, circles show $\langle N(N-1)\rangle^{1/2}/\langle N\rangle$, indicating the width of the probability distribution, for all galaxies (*filled circles*) and satellite galaxies (*open circles*). For Poisson $P(N|M)$, this ratio would be 1 (*dotted curve*). This figure can be compared to Fig. 4 of K04.

Zheng et al. (2005), ApJ, 633, 791.

Fitting Calculated HOD with Five-Parameters Model

- For the fit we used:

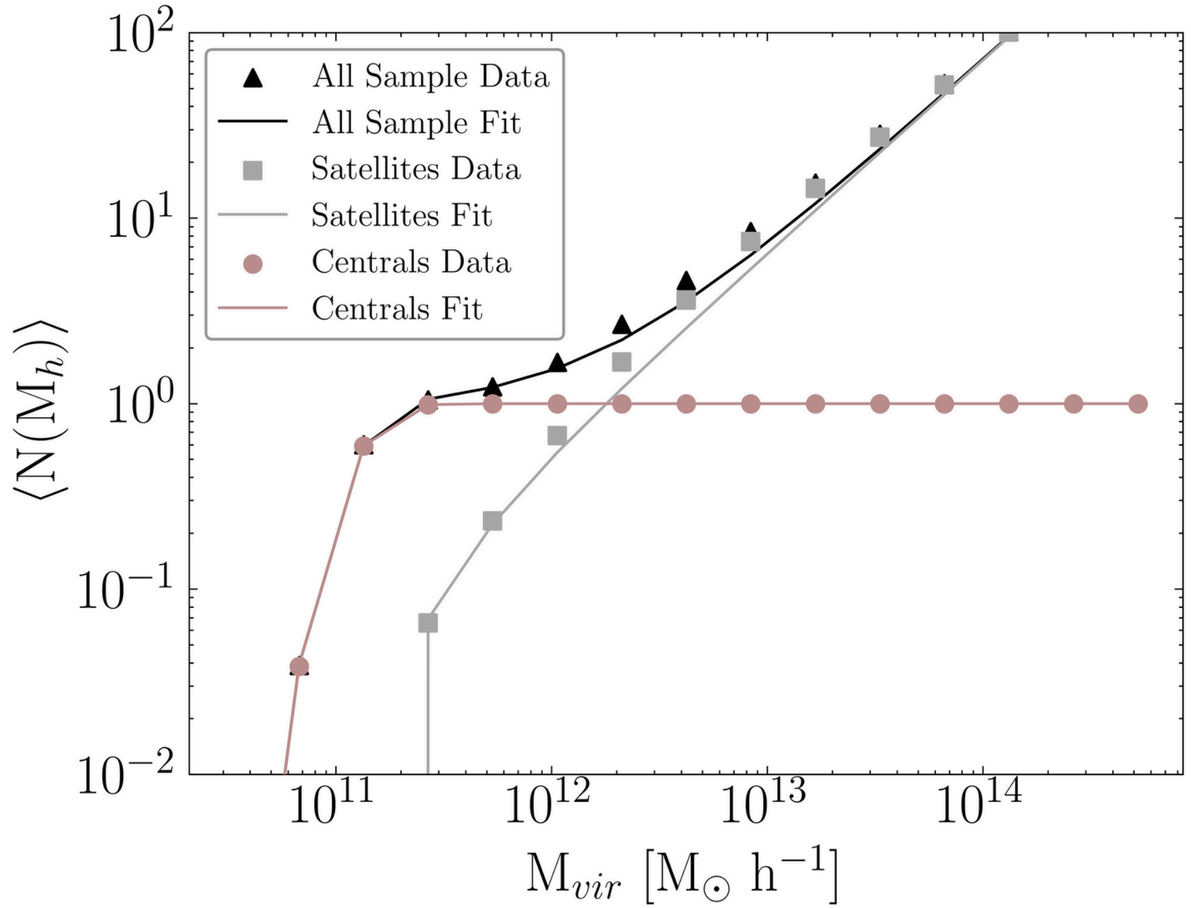
$$\langle N_{\text{cen}}(M_h)\rangle = \frac{1}{2}\left[1 + \text{erf}\left(\frac{\log(M_h) - \log(M_{\text{min}})}{\sigma_{\log M}}\right)\right]$$

In where:

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}\,dt$$

$$\langle N_{\text{sat}}(M_h)\rangle = \left(\frac{M_h - M_{\text{cut}}}{M_1}\right)^{\alpha}$$

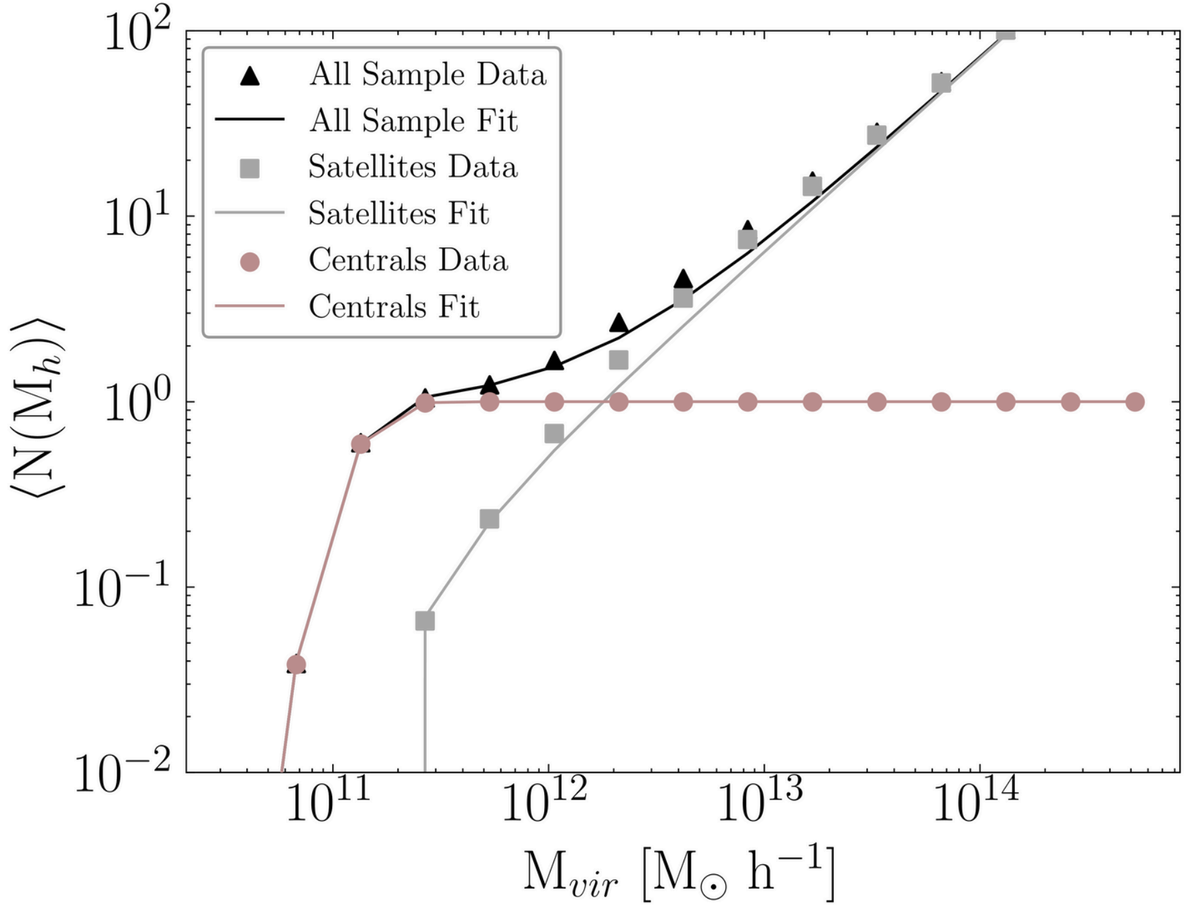
$$\langle N_{\text{all}}(M_h)\rangle = \langle N_{\text{cen}}(M_h)\rangle + \langle N_{\text{sat}}(M_h)\rangle$$



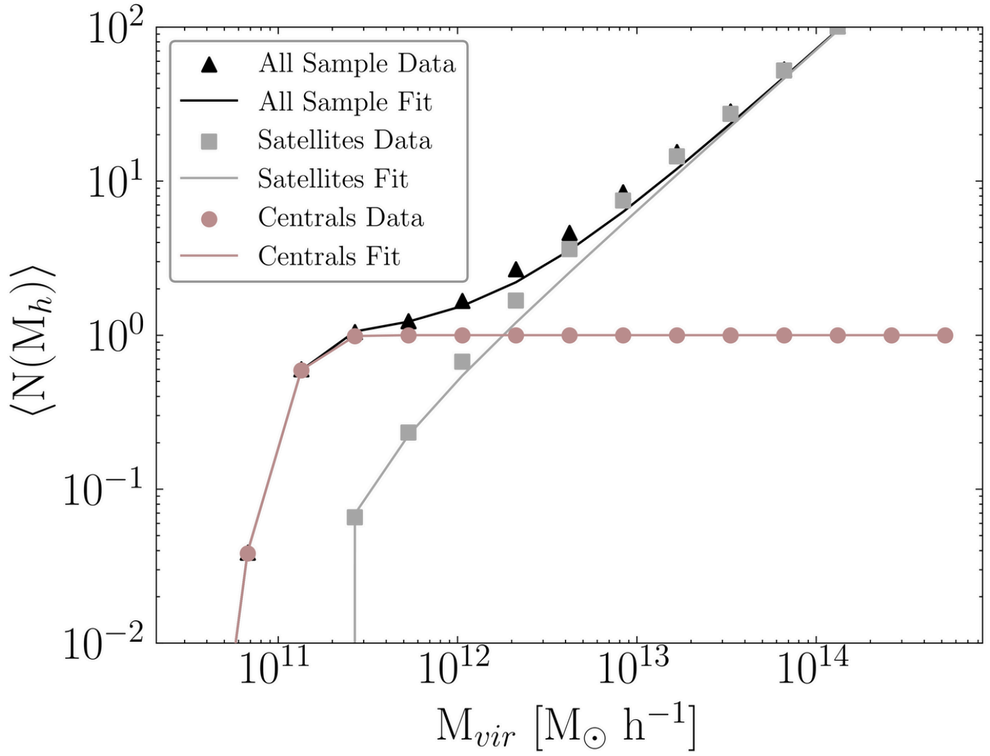
Fitting Calculated HOD with Five-Parameters Model

- The parameter values are:

- log(M_min) = 11.0931 ± 0.0003
- σ_logM = 0.212 ± 0.001
- M_cut = 11.15 ± 2.09
- M_1 = 12.22 ± 0.08
- α = 1.0 ± 0.3



Fitting Calculated HOD with Five-Parameters Model



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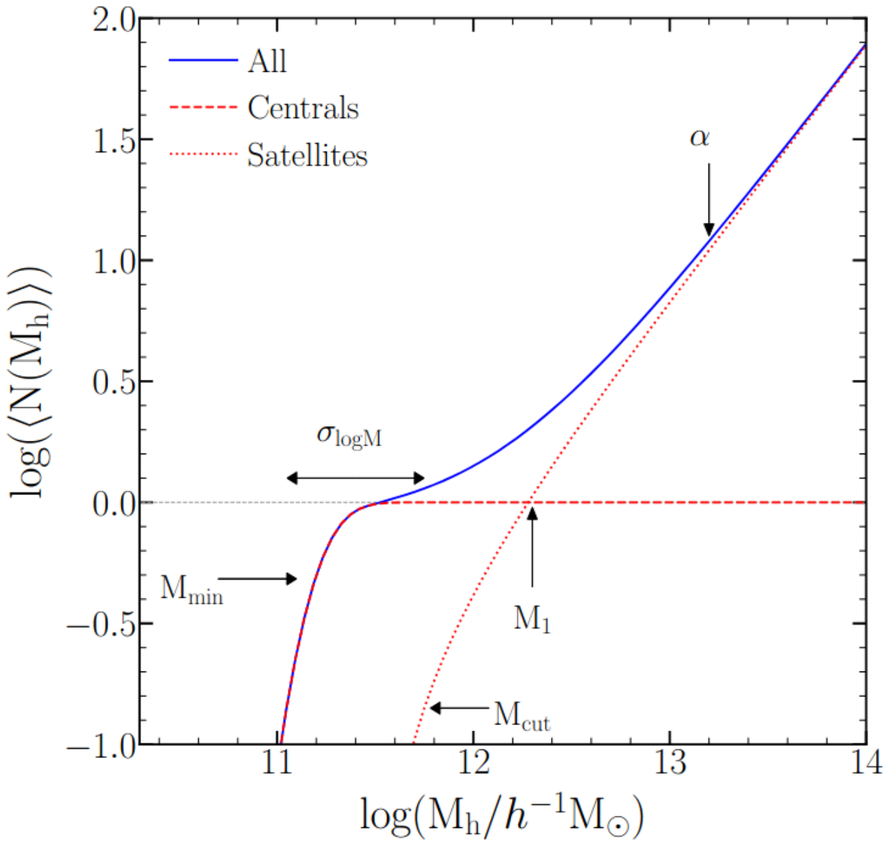
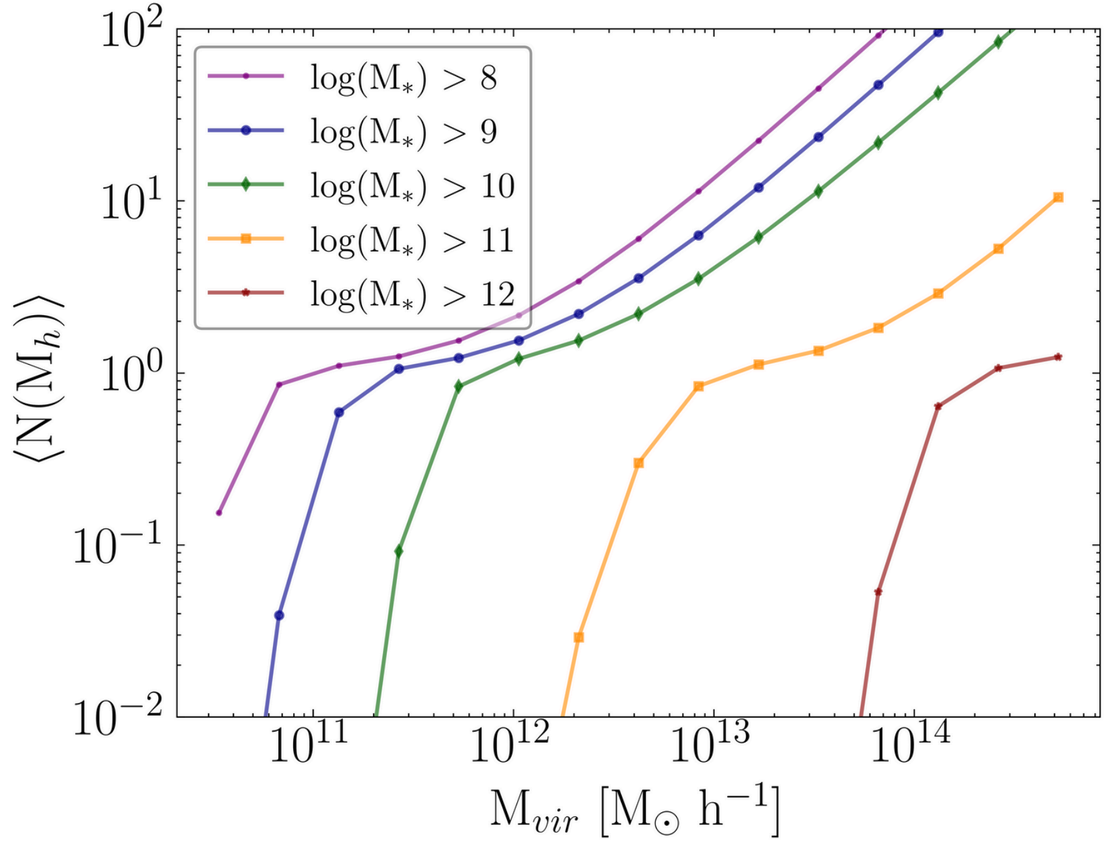


S. Contreras et al. (2023)

Comparisons Between TNG300 & Observations



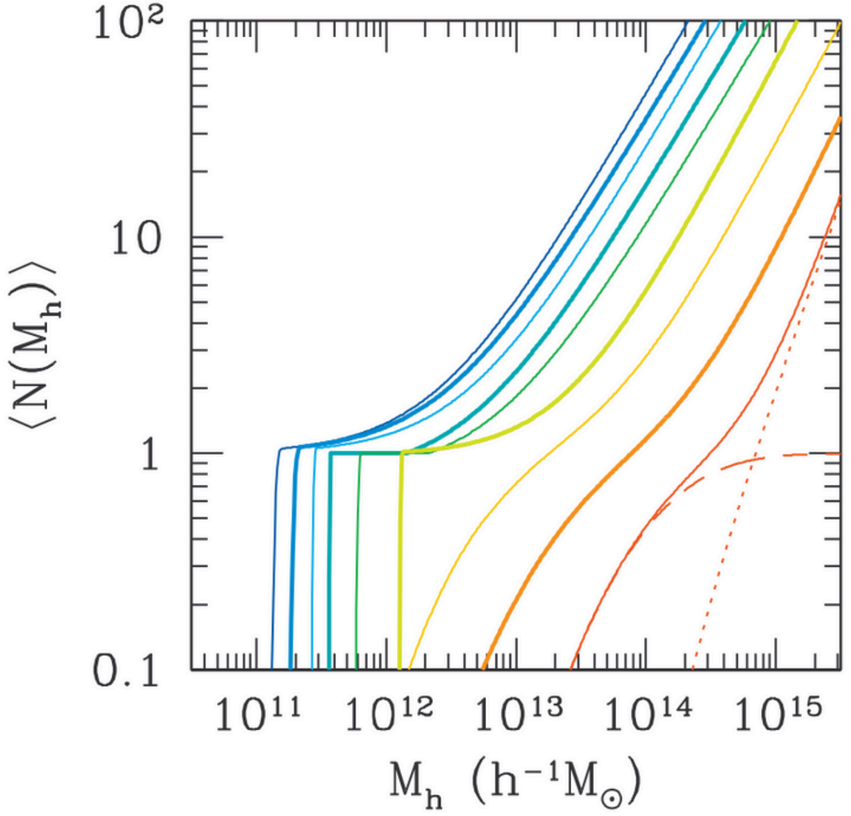
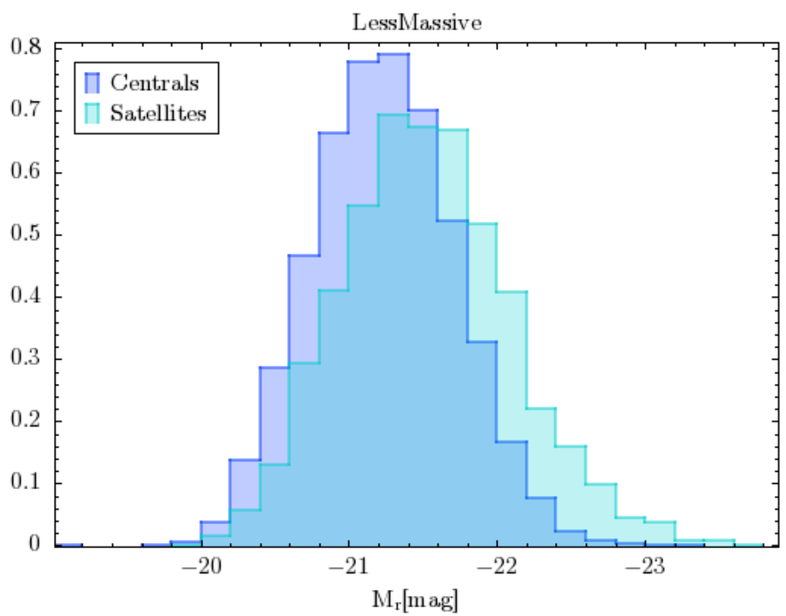


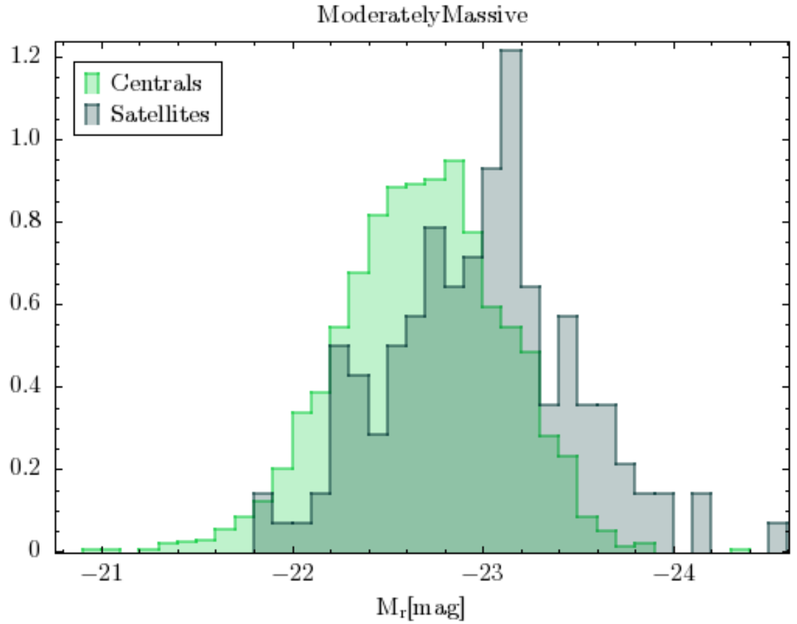
Figure: Blue line (M_r < -18) , orange line (M_r < -22)

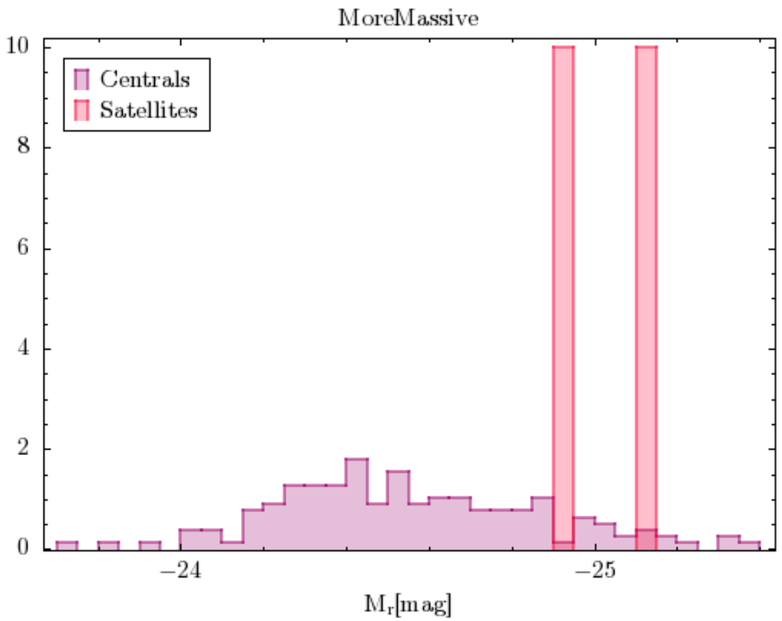
Zehavi et al. (2011) - SDSS

Comparisons Between TNG300 & Observations

- If we check their luminosity, we have:



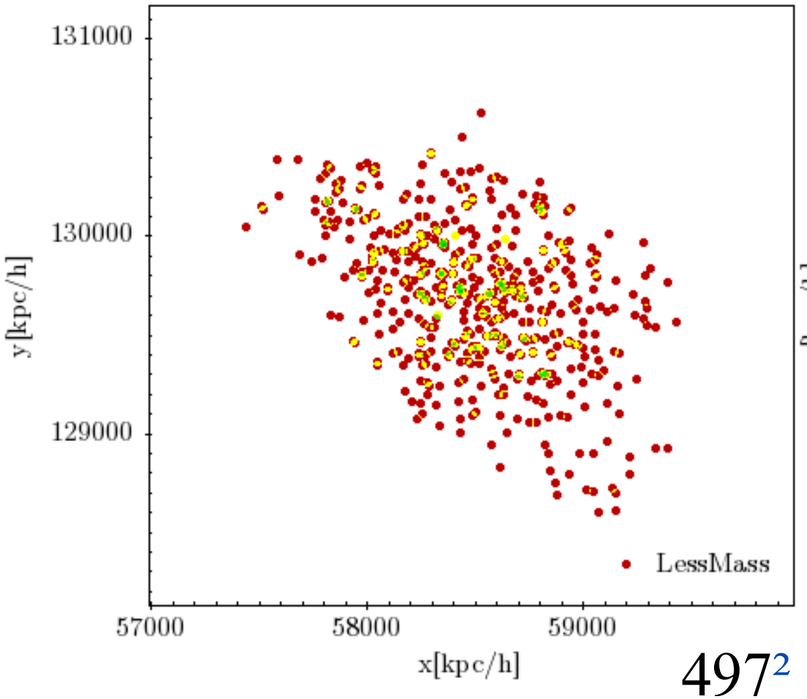




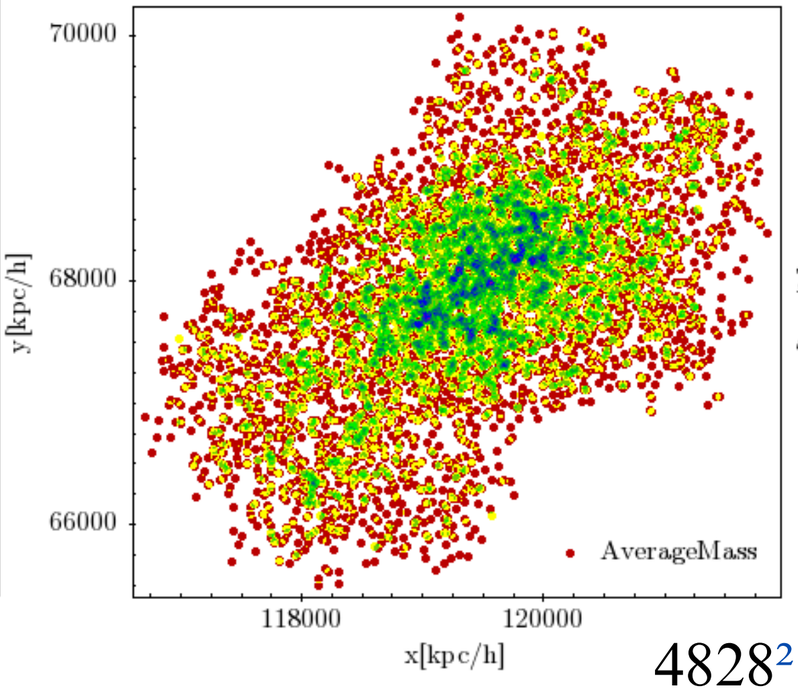
- **Less Massive**: $[1 \times 10^{12}, 3.162 \times 10^{12})\ [M_\odot/h]$
  - Total quantity: 22,682
- **Moderately Massive**: $[1{\times}10^{13}, 3.162{\times}10^{13})\ [M_\odot/h]$
  - Total quantity: 2,169
- **More Massive**: $[1 \times 10^{14}, 3.162 \times 10^{14})\ [M_\odot/h]$
  - Total quantity: 158

Clustering & Correlation Function

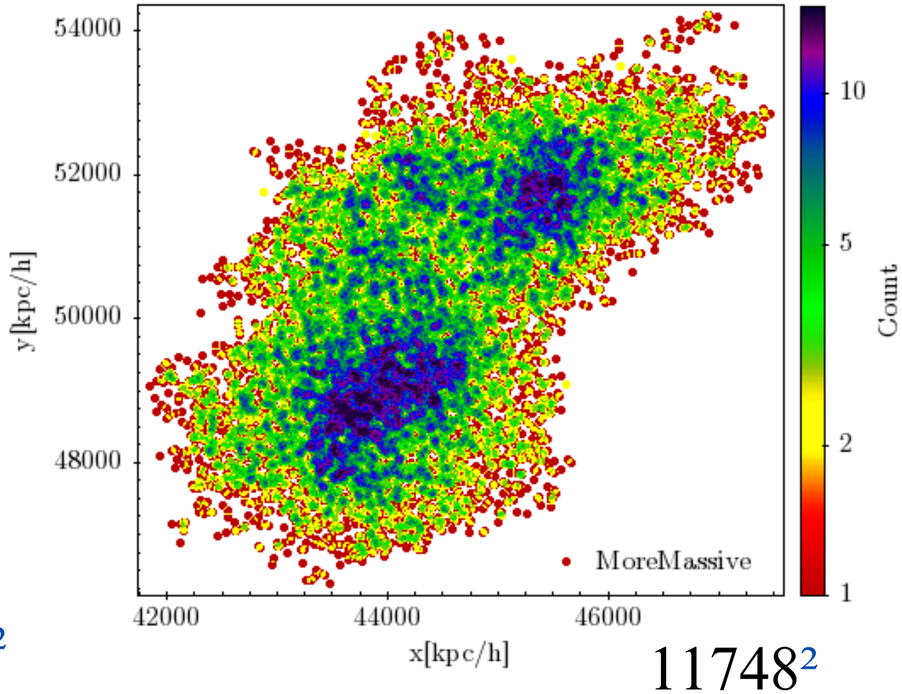
- A simple view: Approximating the length of halos in TNG300



497^2



4828^2



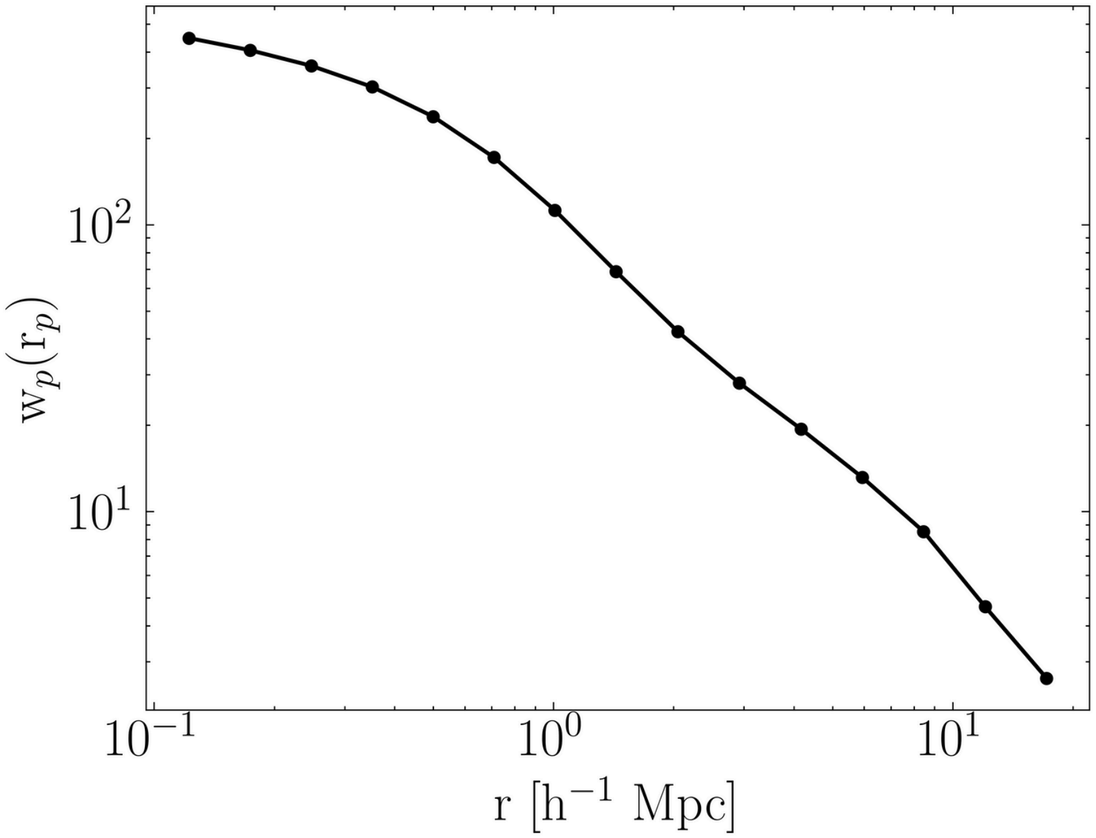
11748^2

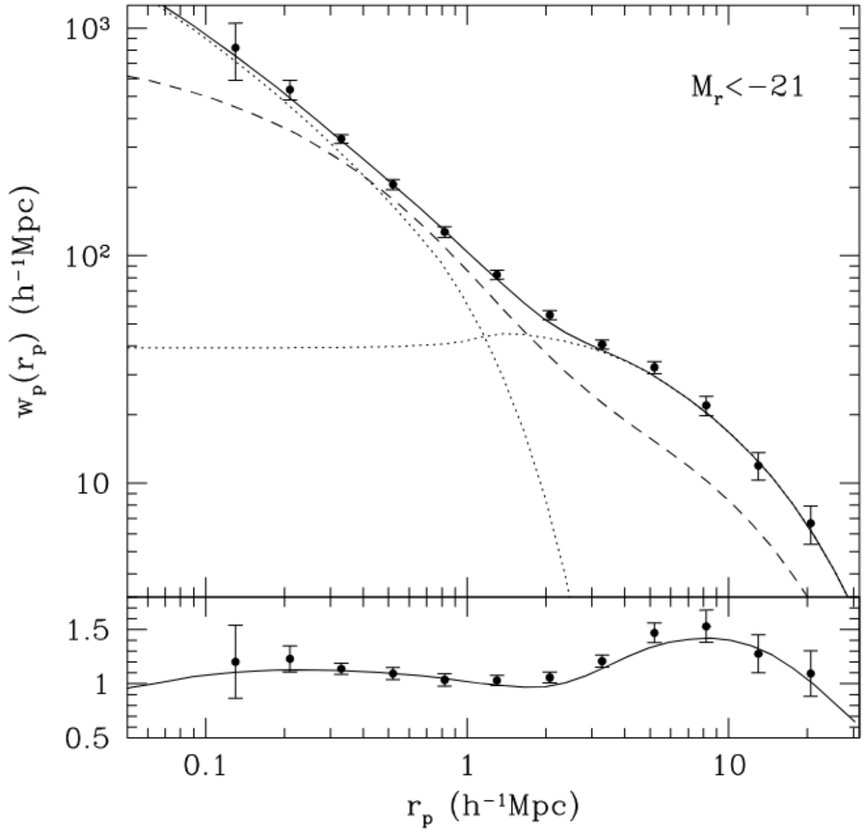
- If we use the number of subhalos to determine their length, we have ≈ 1 - 4 Mpc

[2]Number of subhalos

Correlation Function & HOD Model

- Using Corrfunc tool for the Correlation Function





Zehavi et al. 2003

¡Conclusions!

References

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Zheng, Z., Berlind, A. A., Weinberg, D. H., et al. 2005, ApJ, 633, 791