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Predicting Stellar Masses of Low Mass Satellites from DMO Simulations

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Numerical Galaxy Simulations

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- N-body simulations containing different particles representing gas, stars, and matter interact and evolve
- Observing their evolution over time till t = 13.6 Gyr using supercomputers
- NIHAO (Numerical Investigations of hundred Astronomical Objects) - UHD simulations

NIHAO - UHD simulations

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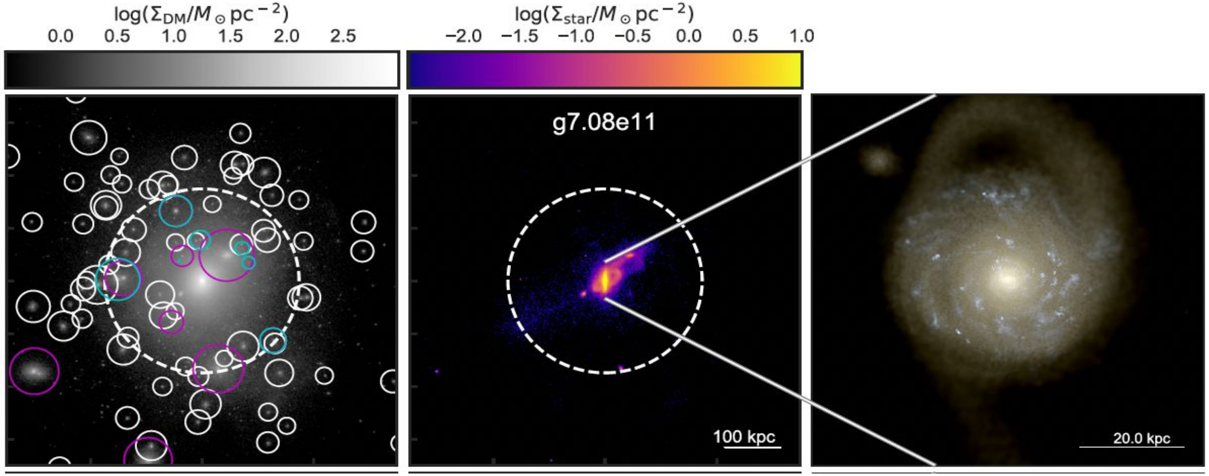
- Ultra High Definition ($N_{part} > 10^7$)
- For potential small scale structures
- Low-mass Satellites



Buck et al. (2018)

Background

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Hydrodynamical UHD Simulations

- Evolution of Baryonic matter and dark matter
- More complex due to the feedback from various Baryonic processes
- Takes about four months to run

Dark Matter Only UHD Simulations

- Evolution of only dark matter and thus only considers gravity
- Less complex and takes only a few days to run
- But don’t produce stars to compare with observations

A Tool to assign stellar populations to halos in DMO simulations

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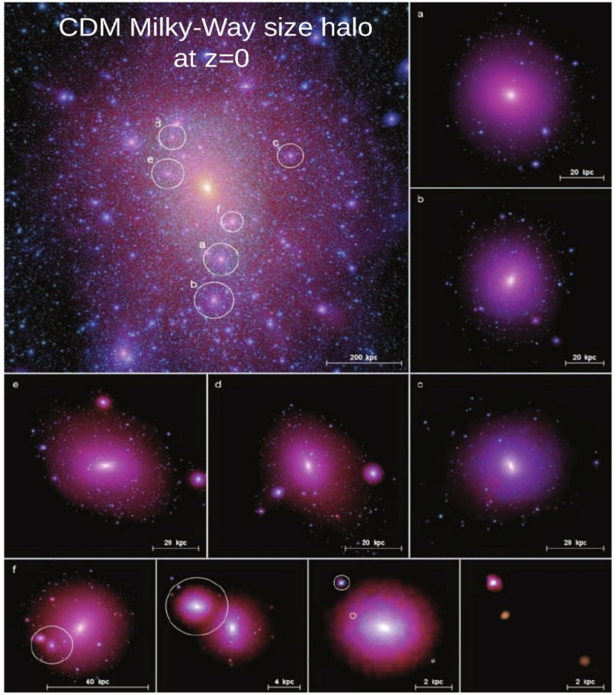
Stellar mass prediction tool for satellites which don't follow the traditional stellar mass relation

Subhalos gravitationally bound to the central galaxy, like the Milky way

3 Training Galaxies and 3 Testing Galaxies



Zavala et al. (2019)

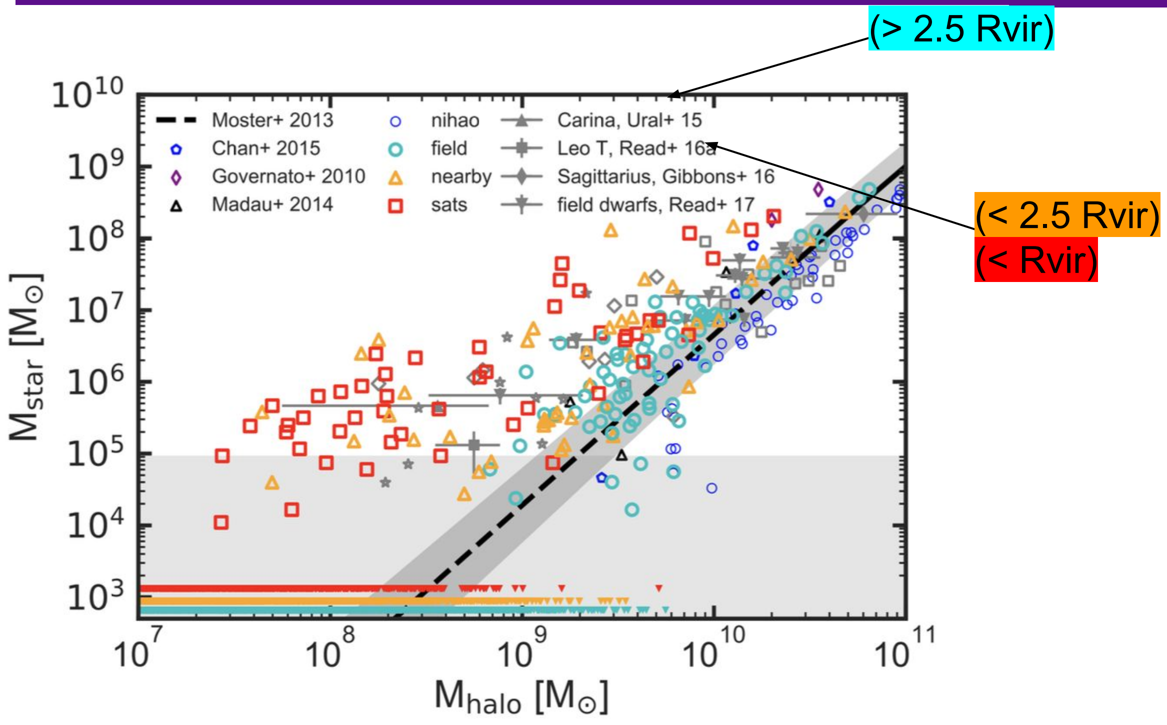
Motive

To quickly and efficiently test different Dark Matter models

using the DMO simulations

DMO Simulations output → Tool to assign stellar mass to Dark Matter Satellites → A portion of Hydrodynamical Simulations Output

Existing Stellar Mass relation



Buck et al. (2018)

- Nearby Satellites indicating evidence for total mass loss but retaining stellar mass
- Ram Pressure Stripping
- Total Halo Mass at z = 0 not sufficient to predict Stellar Mass

→ The maximum Halo Mass (M_peak) the Satellite has obtained throughout its time

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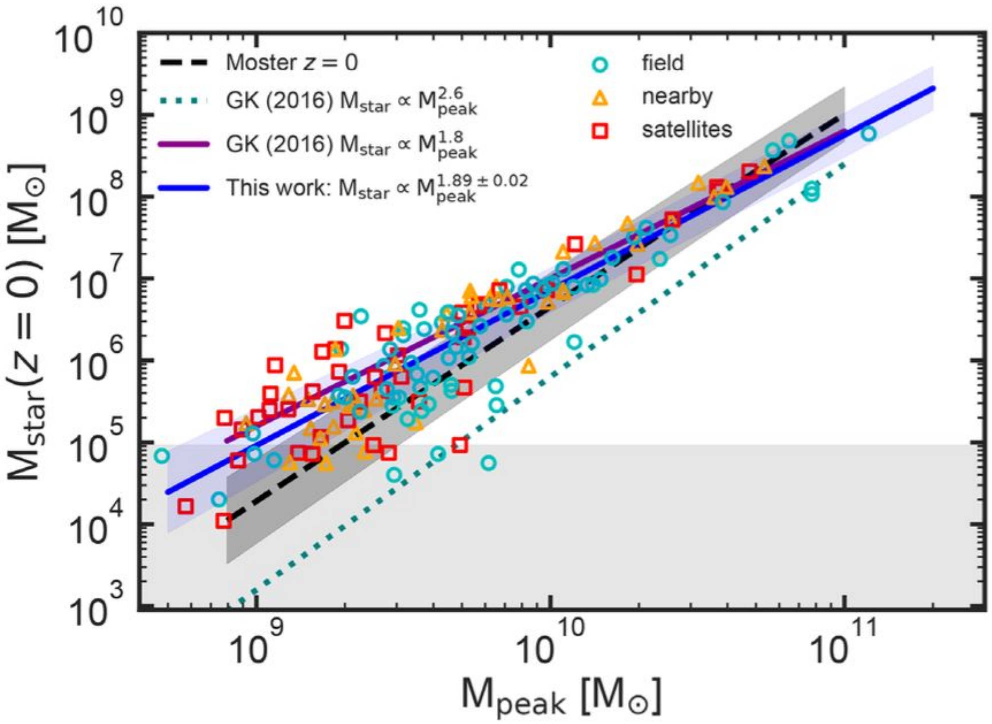

- Stellar mass today vs. Maximum Total Mass ever reached for nearby galaxies and Satellites

- In this project we used Maximum circular velocity throughout time by tracking the evolution of V_{circ} using Merger Trees

$$V_{max} = \sqrt{\frac{GM_{peak}}{R}}$$

Buck et al. (2018)

The Prediction Tool

- Adjusting the differences in the number of satellites in DMO and Hydro simulations
- A Probability distribution to determine whether the Halo is Luminous or not
- Obtaining the Stellar Mass at Redshift 0 via Maximum Circular Velocity of Satellites over time
- Satellites within 1.5*Rvir from the host Galaxy

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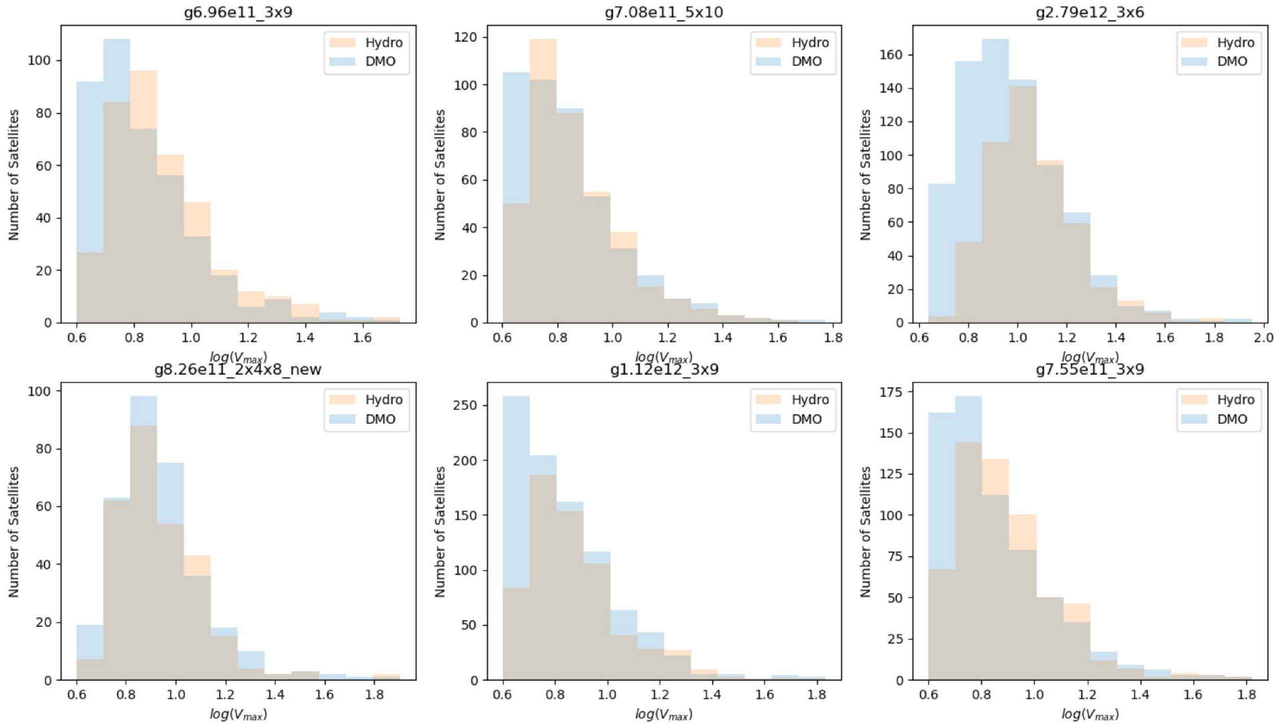
Differences in the Number of Satellites between the two simulations



The effect of the Stellar Disk present in the Hydro Simulations

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- Smaller halos are more likely to be destroyed by the Stellar Disk
- Larger Halos are expected to survive the effect of Stellar Disk

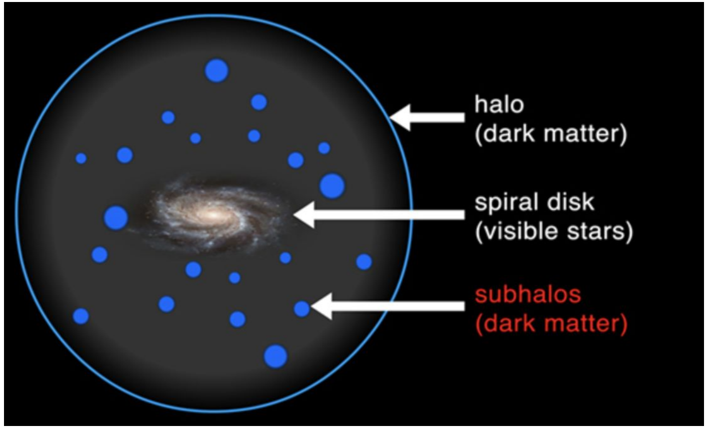
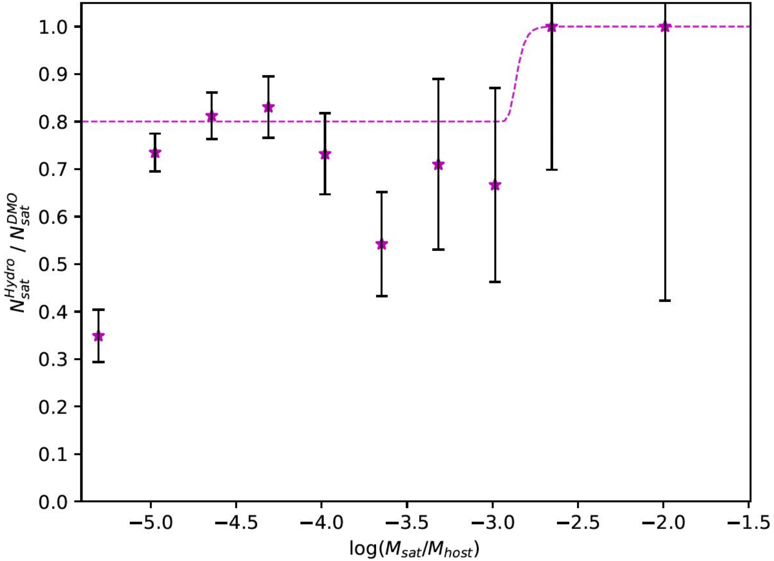


Image source: https://kids.frontiersin.org/

Data obtained from 3 UHD galaxies



$$N_{hydro}/N_{dmo} = \begin{cases} 0.75, & min < log(M_{sat}/M_{host}) < -3 \\ 1, & -3 > log(M_{sat}/M_{host}) < max \end{cases}$$

Dark Fraction

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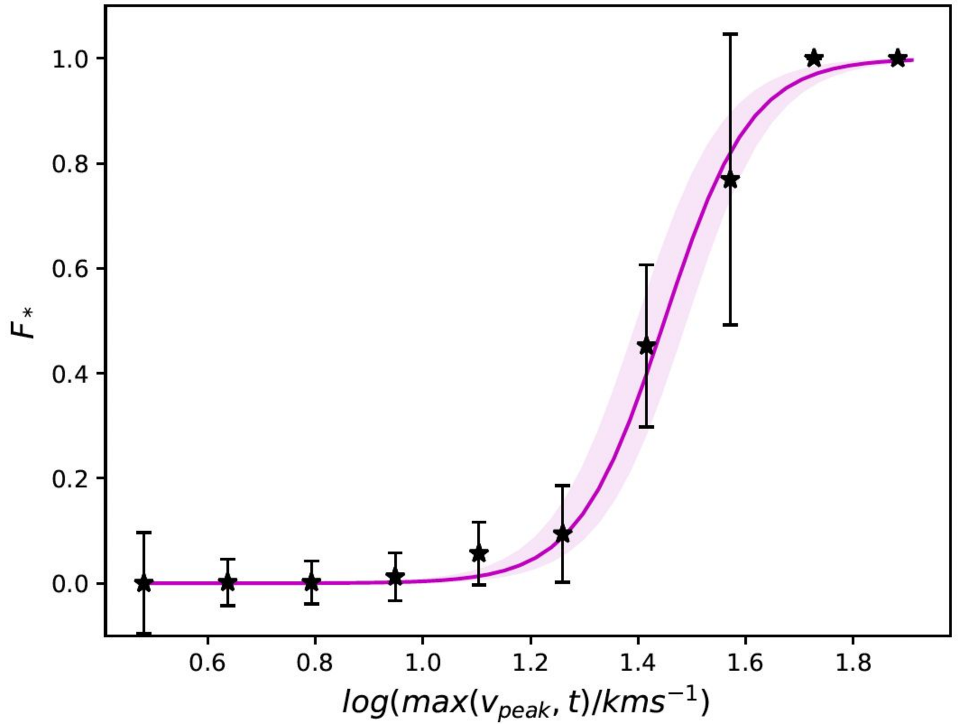
- Probability of a satellite to be luminous inferred based on their Max Circular Velocity
- Approaches 0 for smaller Halos and goes to 1 for larger Halos.

$$F_* = \frac{1}{(1 + e^{-A*(logV_{max} - V_0)})}$$

$$A = 12.89^{+0.05}_{-0.06}$$
$$V_0 = 1.34^{+0.05}_{-0.05}$$

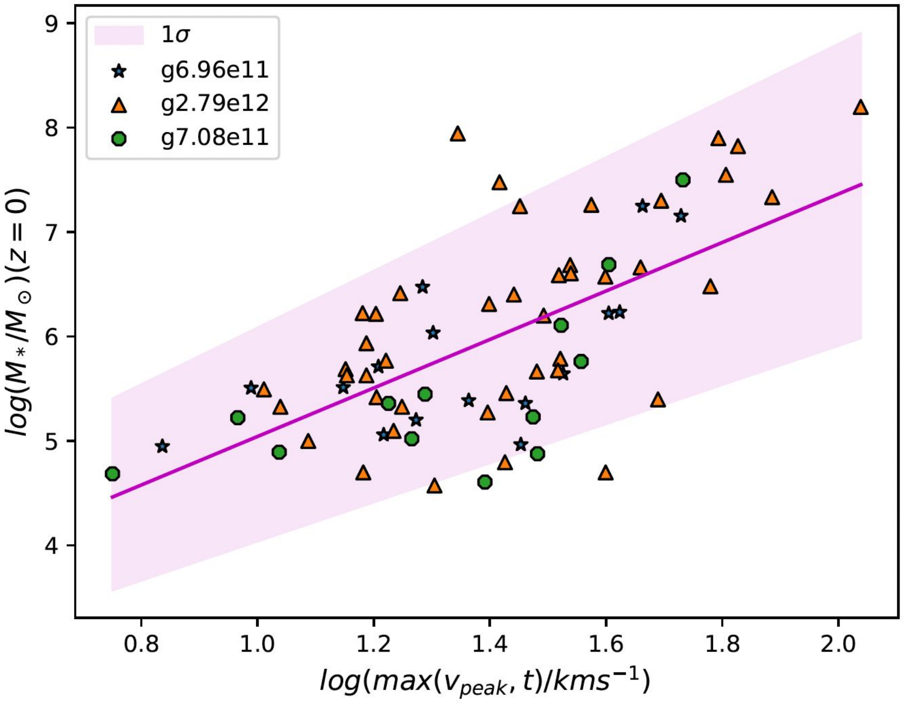


Stellar Mass Matching Relation

- Assigning Stellar Mass of the luminous satellites at z = 0 using their Maximum circular velocity throughout time
- Relation between the Stellar Mass at z = 0 and V_max throughout time

$$logM_{star} = A * logV_{max} + B$$

$$A = 2.33^{+0.38}_{-0.43}$$
$$B = 2.70^{+0.61}_{-0.38}$$



DMO

Hydro

Input :

- Maximum Circular velocity throughout time
- Mass of Each satellite at $z = 0$
- Mass of Host at $z = 0$

Prediction Tool →

Output (predictions):

- Number of Luminous Halos
- Stellar masses of luminous Halos
- Radial Distribution

Procedure

Input : V_{max}, (M_{sat}, M_{host}) from DMO simulations for each satellite

Two probabilities :

Dark Fraction:

$$F_* = \frac{1}{(1 + e^{-A*(logV_{max} - V_0)})}$$

Hydro/DMO satellites number ratio:

$$N_{hydro}/N_{dmo} = \begin{cases} 0.75, & min < log(M_{sat}/M_{host}) < -3 \\ 1, & -3 > log(M_{sat}/M_{host}) < max \end{cases}$$

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[0 1 0 1 1 0 1 0 1 1 1 1 1 1 1 1 0 1 0 1 1 1 0 0 1 0 1 1 1 1 1 1 1 0 1 1 1
 1 0 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 0 0 1 0 1 1 1 1 1 1 1 1 1
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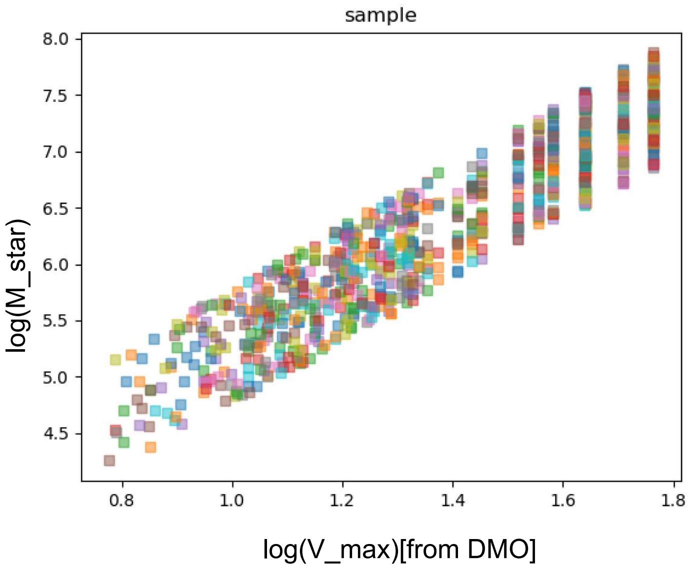
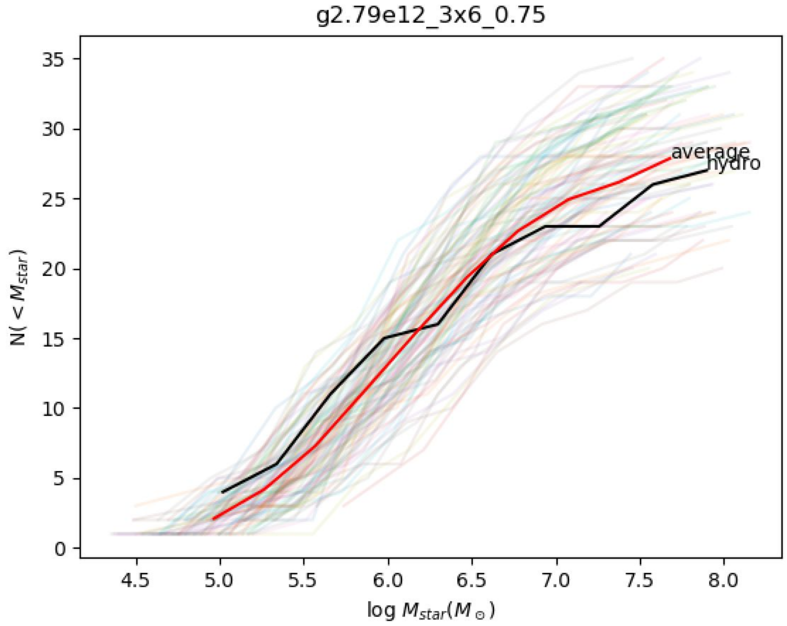
Assigning M_star

$$logM_{star} = 2.58 * logV_{max} + 2.47$$

\+ One sigma Confidence interval ([-0.58, +0.58])



Cumulative Stellar Mass function



Satellite Stellar Mass Function

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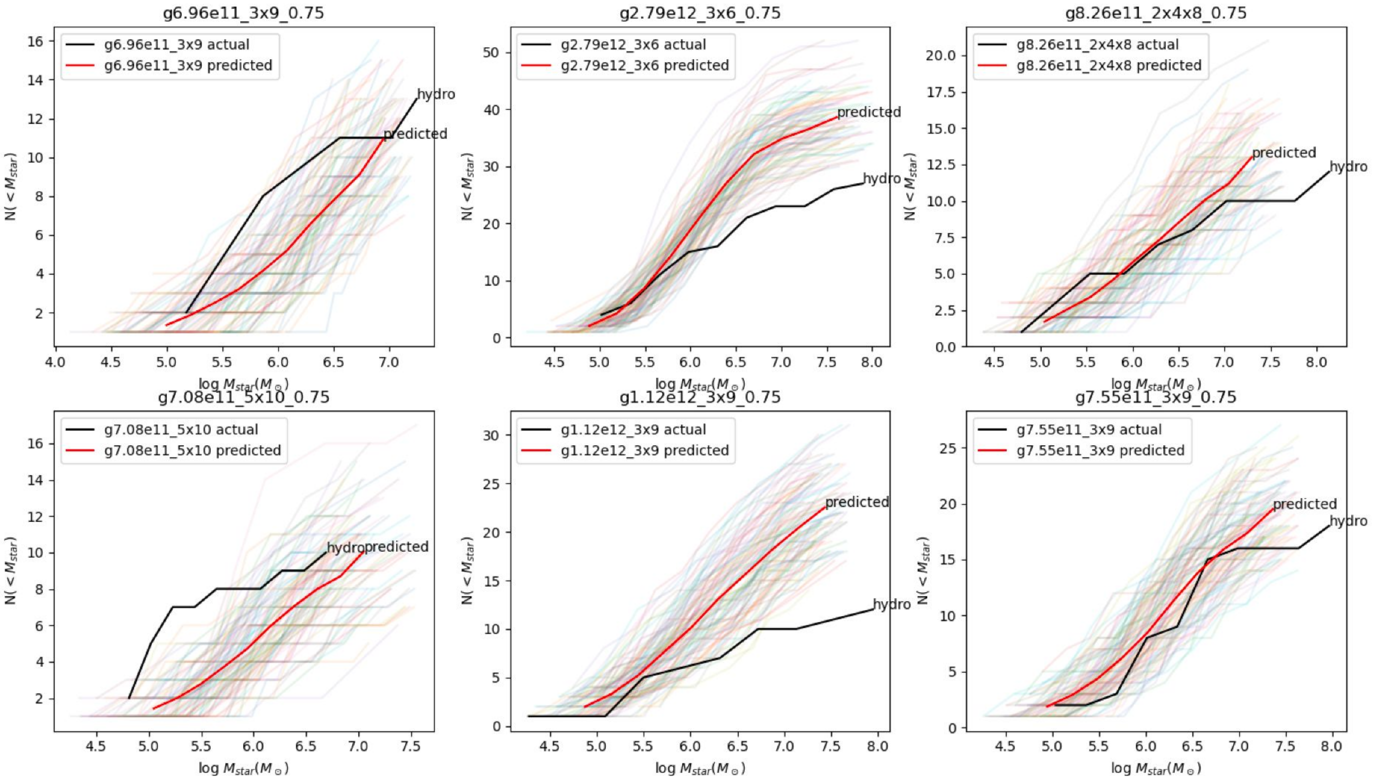
Training Galaxies : →

Testing Galaxies : →



Radial Distribution (DMO V_{max} as input)

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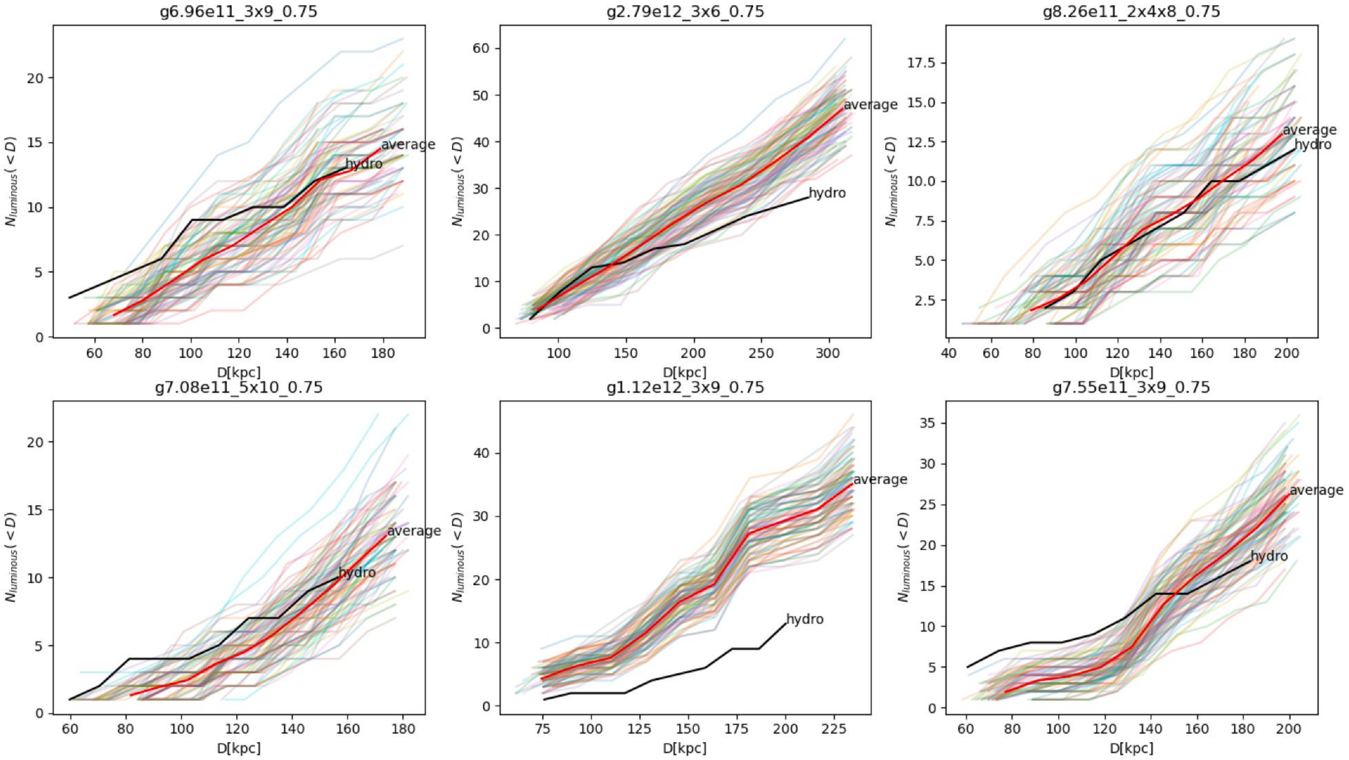
Training Galaxies : →

Testing Galaxies : →



The Bias in predictions

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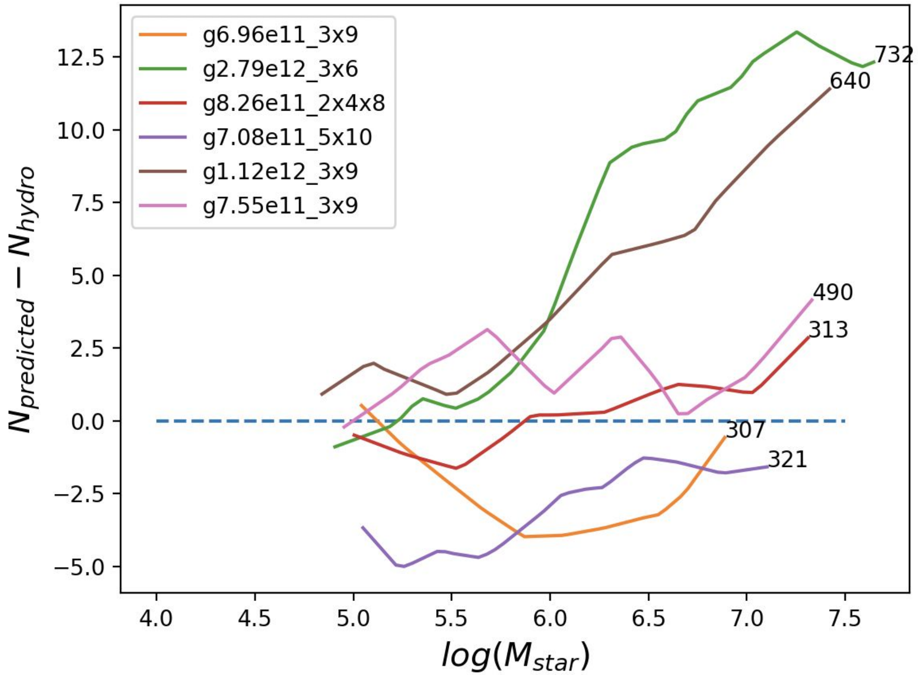


Number of satellites within 1.5*Rvir

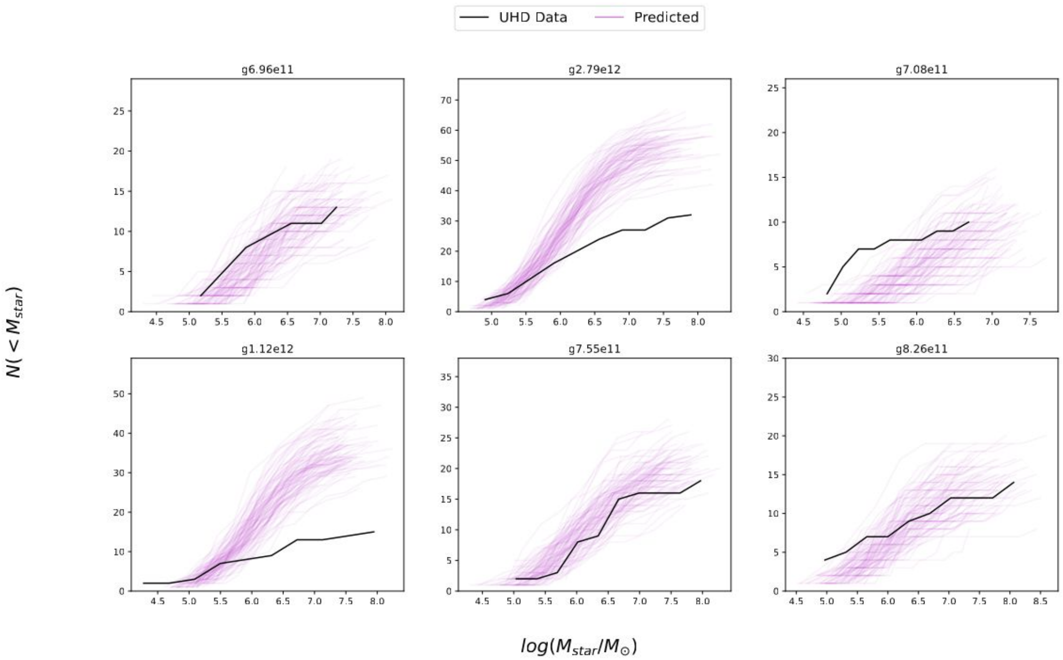
$$F_* = \frac{1}{(1 + e^{-A*(logV_{max} - V_0)})}$$

$$A = 12.89^{+0.05}_{-0.06}$$
$$V_0 = 1.34^{+0.05}_{-0.05}$$

$$N_{hydro}/N_{dmo} = \begin{cases} 0.75, & min < log(M_{sat}/M_{host}) < -3 \\ 1, & -3 > log(M_{sat}/M_{host}) < max \end{cases}$$

$$logM_{star} = 2.58 * logV_{max} + 2.47$$

- **Overestimations for 2.79e12 & 1.12e12**



Fixing the bias

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Culprit:

Dark Fraction with two parameters

1.2 Dark Fraction

$$F_* = \frac{1}{(1 + e^{-A*(logV_{max} - V_0)})}$$

$$A = 12.89^{+0.05}_{-0.06}$$
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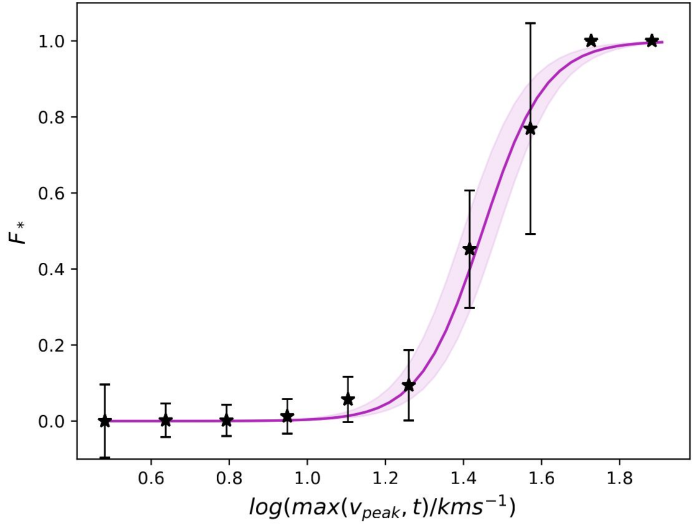
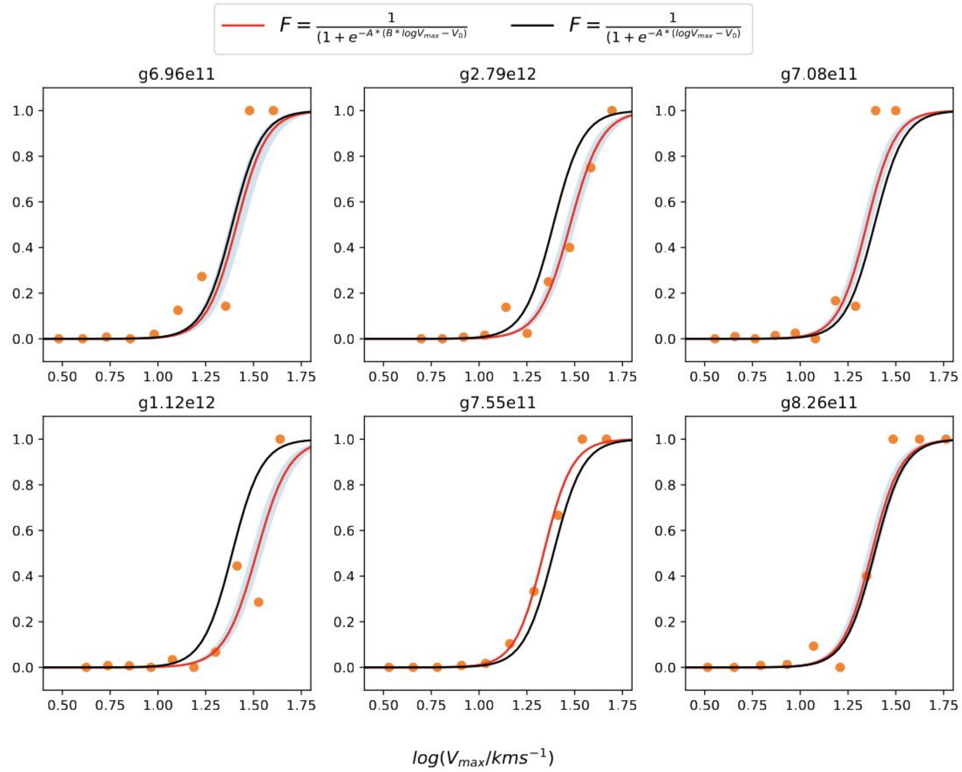


Extra Parameter B

- Fixed A and V_0 , varying B for each galaxy
- A new parameter dependent on galaxy size and satellite numbers



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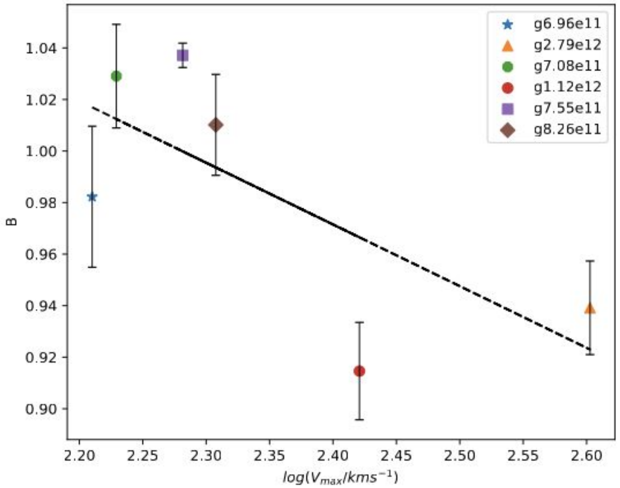
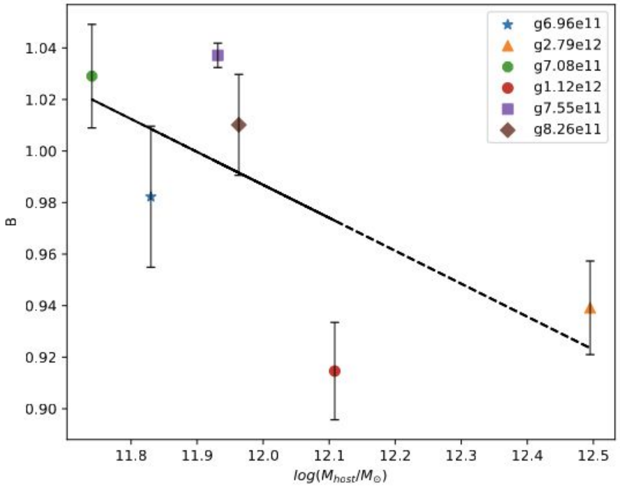
Correlation of B with V_{max} & M_{host}





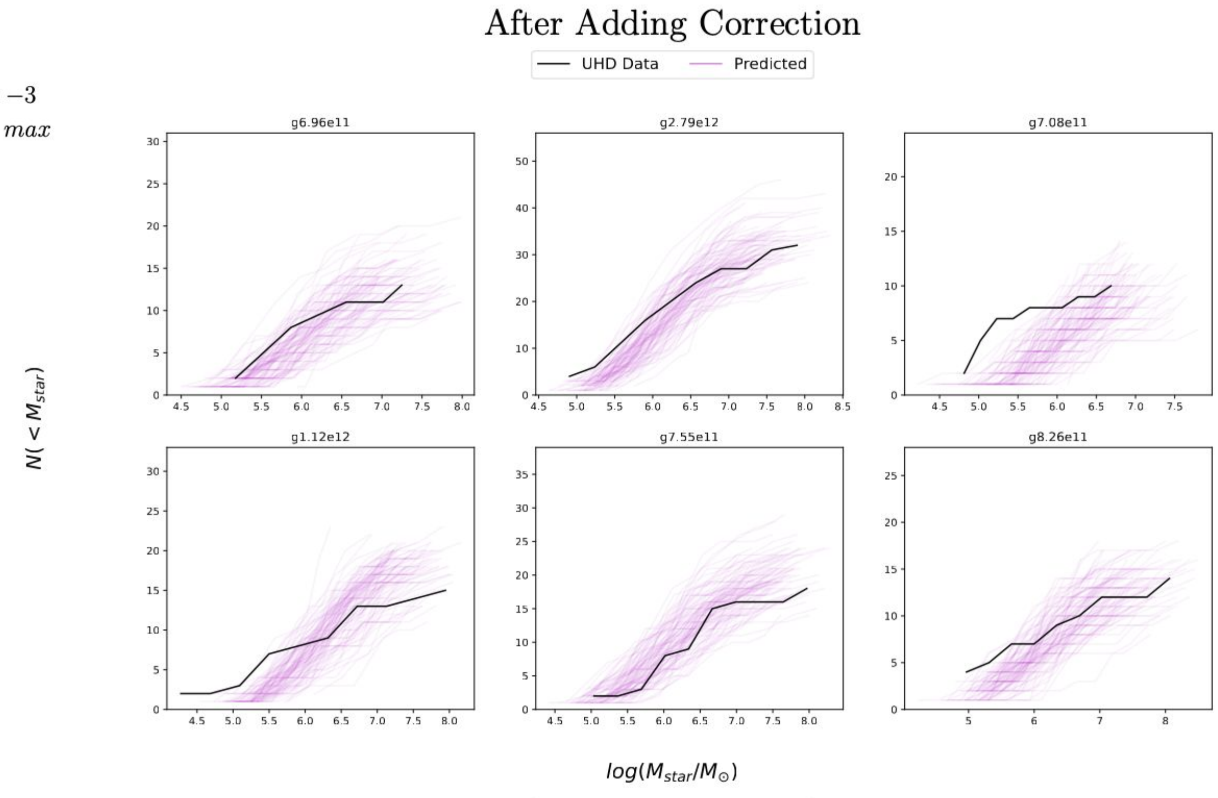
Final Results

$$N_{hydro}/N_{dmo} = \begin{cases} 0.75, & min < log(M_{sat}/M_{host}) < -3 \\ 1, & -3 > log(M_{sat}/M_{host}) < max \end{cases}$$

$$logM_{star} = 2.58 * logV_{max} + 2.47$$

$$F = \frac{1}{(1 + e^{-A*(B*logV_{max} - V_0)})}$$

B ~ 0.92 for $M_{host} > 10^{12}\ M_{sol}$



Radial Distribution

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