Self-similar decomposition of the hierarchical merger tree of dark matter halos

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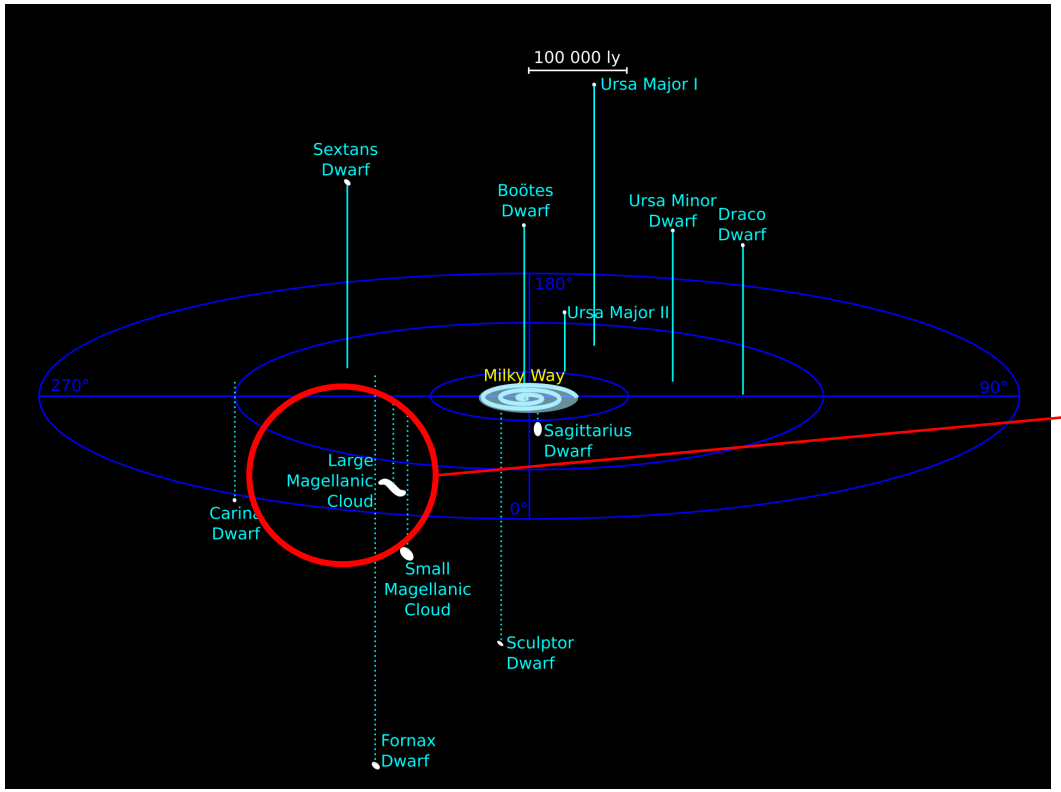
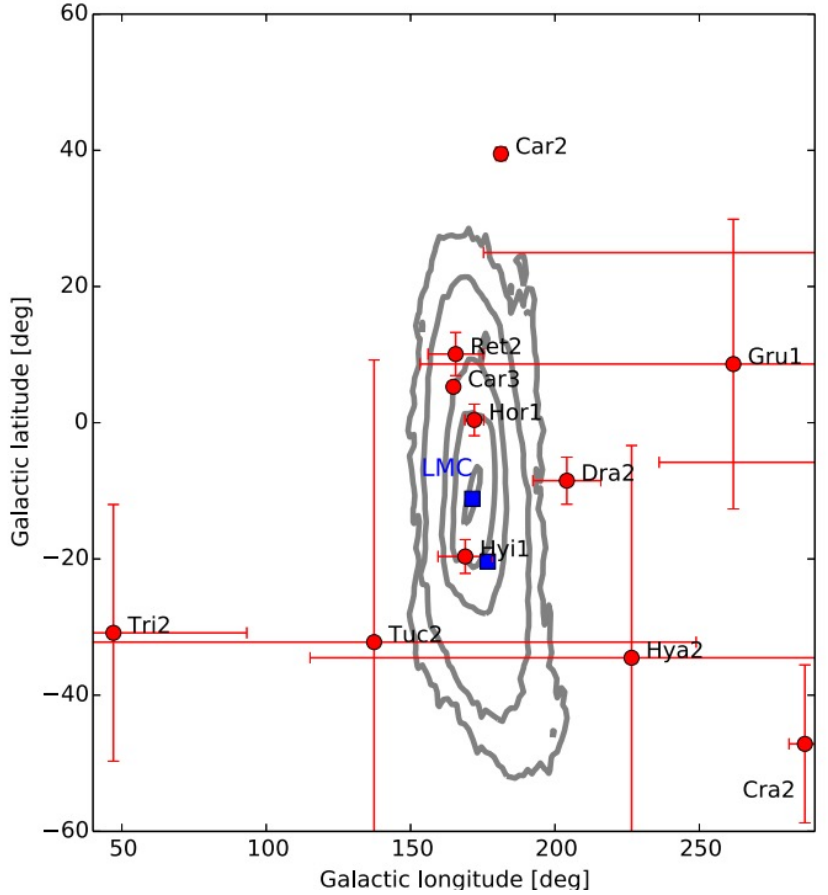
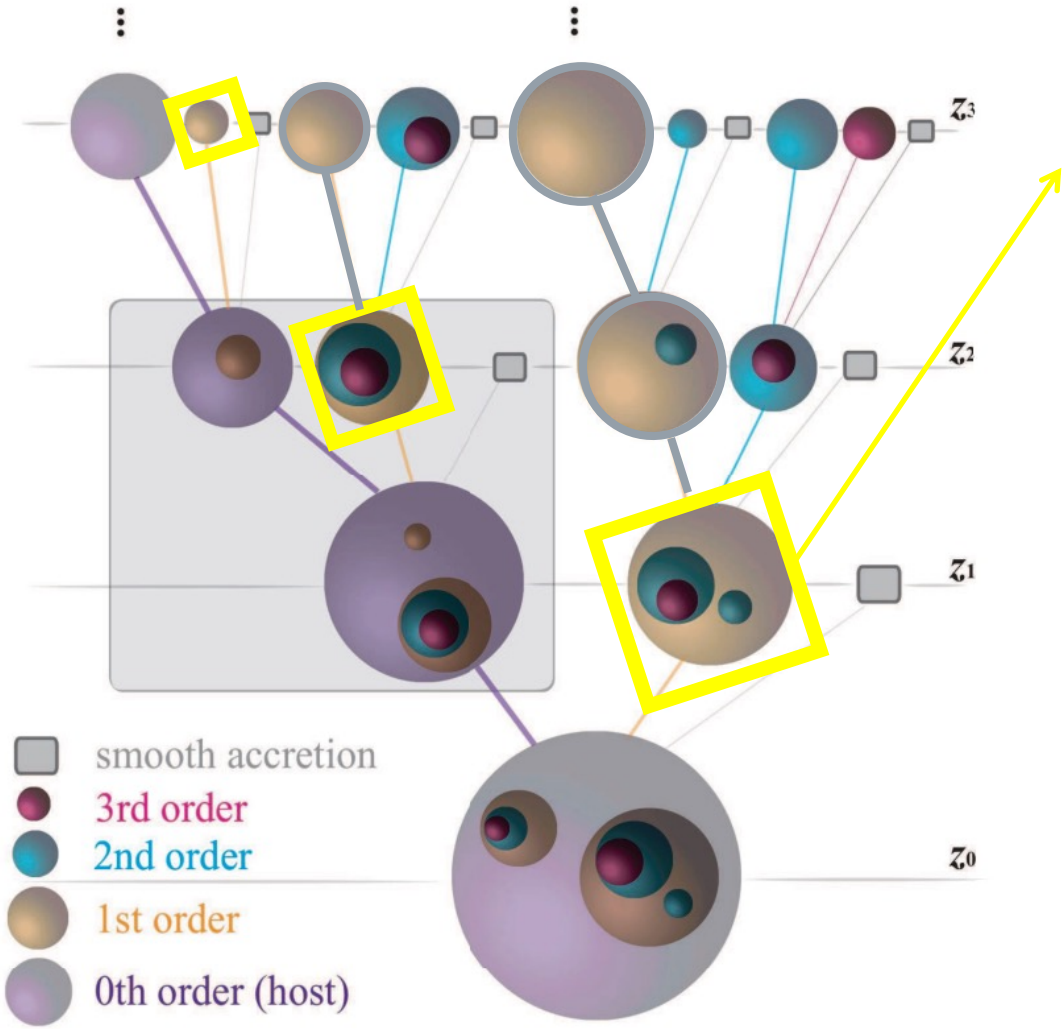
Hierarchical Universe





Kallivayalil el al. 2018

The Halo Merger Tree

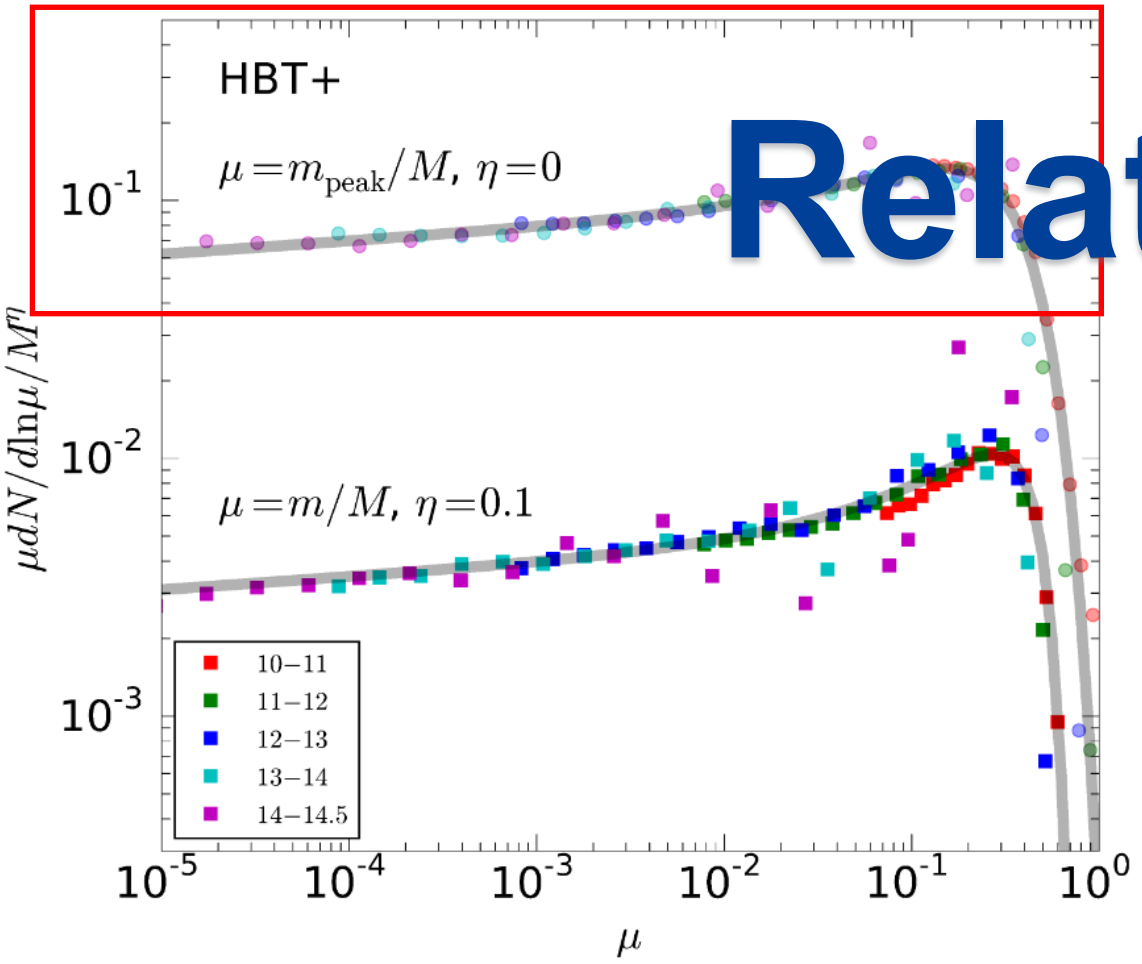


m_{peak} maximum mass of progenitors reached in their histories

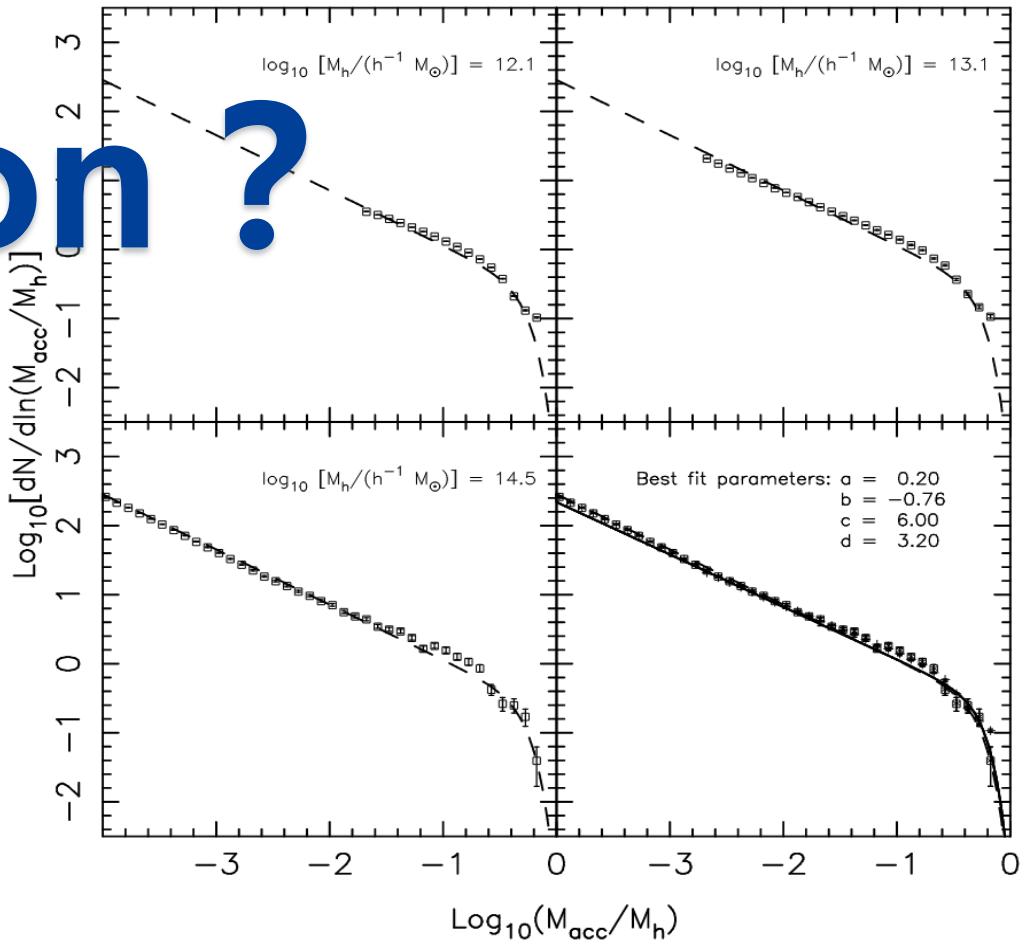
The subhalo Peak Mass Function(PMF)

Studies on PMFs

All level ⟷ Level 1



Relation ?



Han et al. 2018

Li & Mo 2009

Simulation & Subhalo Finder

LCDM Simulation

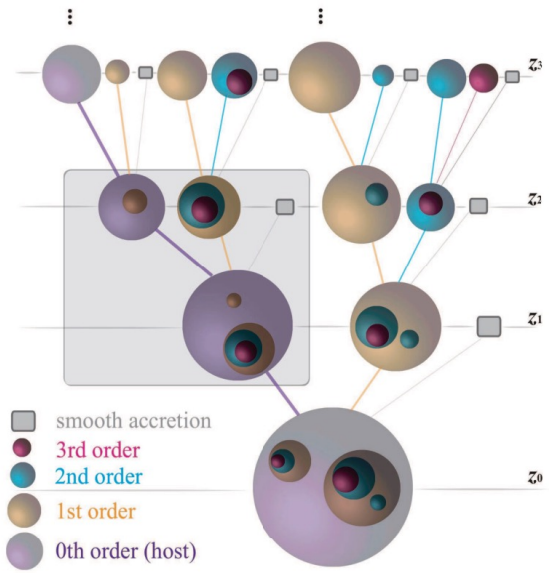
$$L_{\rm box} = 600{\rm Mpc}\,h^{-1}$$

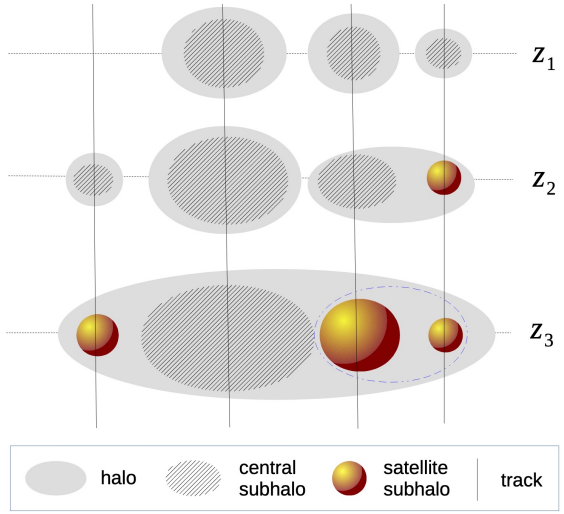
$$m_{\rm p} = 5.5 \times 10^8 M_\odot\,h^{-1}$$

$$N_{\rm p} = 3072^3$$

`depth`: level of subhalos according to the merger history

HBT+

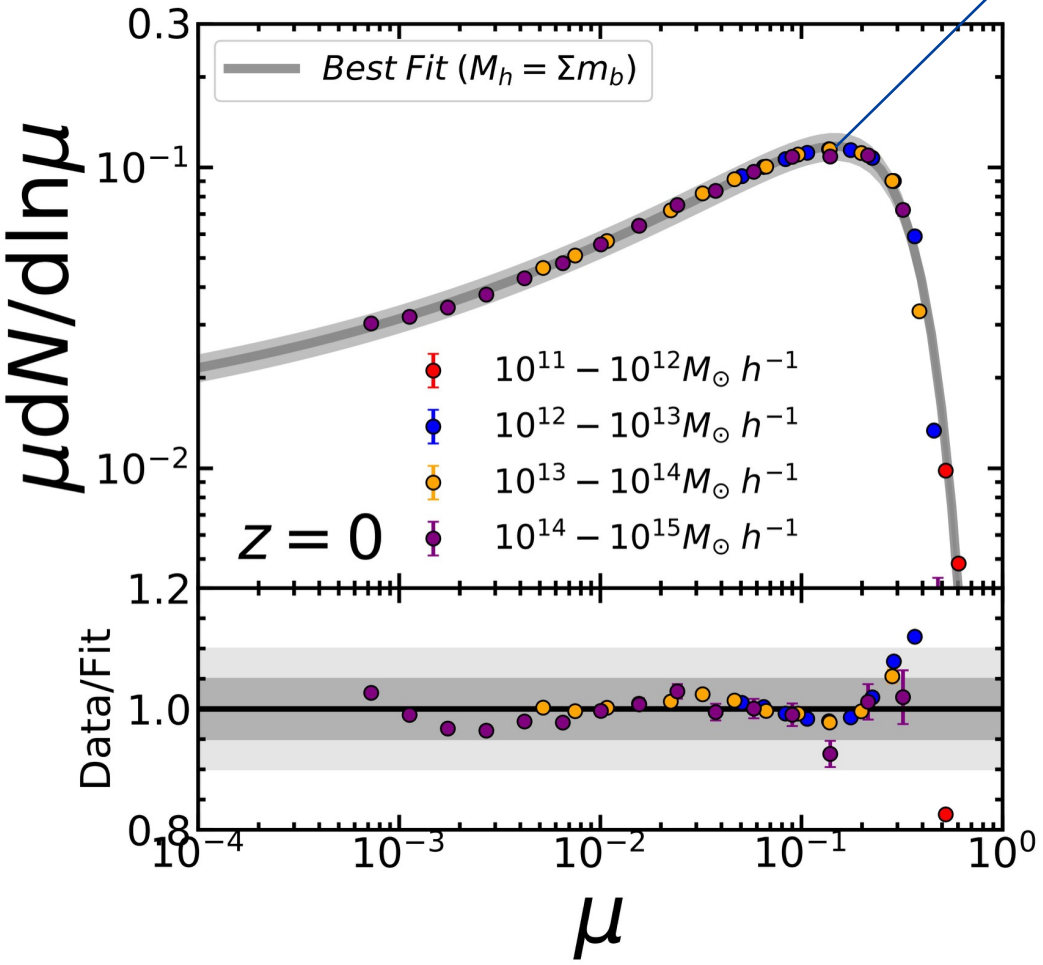




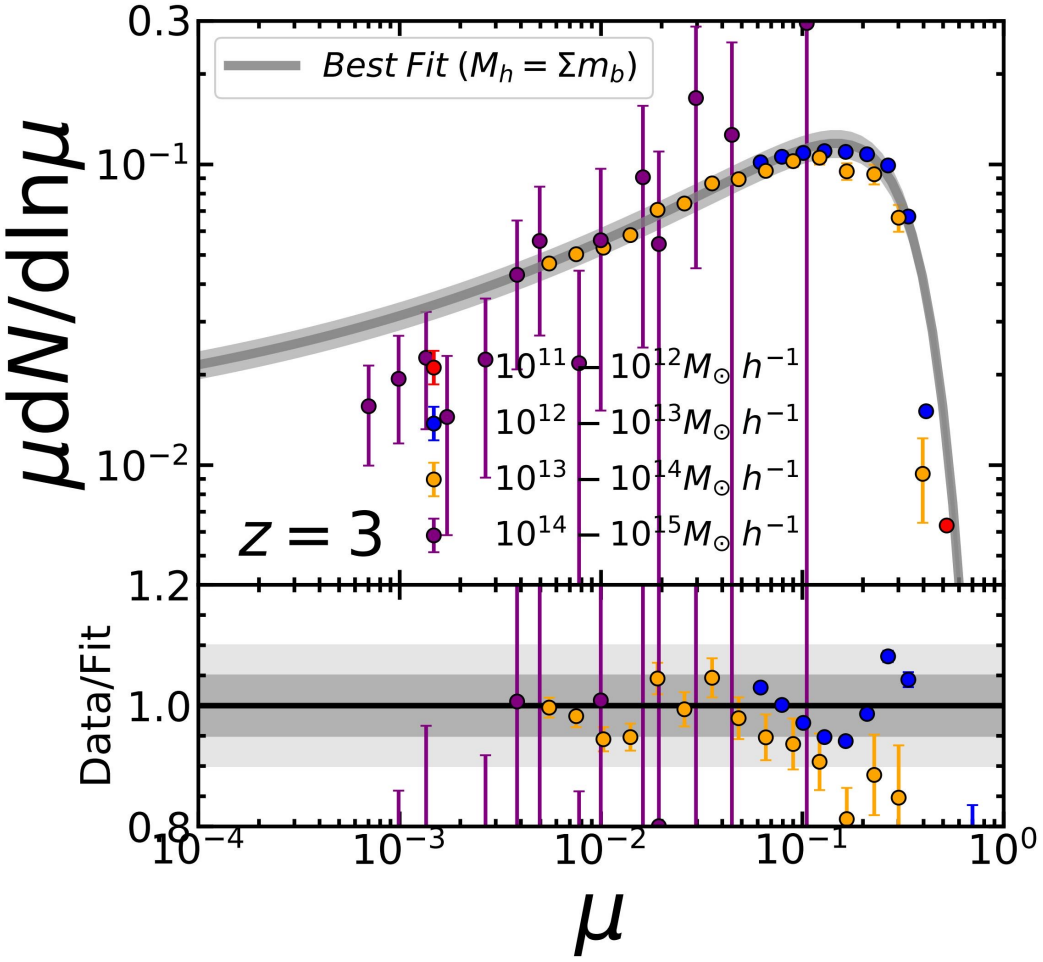
(Han et al. 2018)

The universality of the level-1 PMF

$$g_1(\mu) = (a_1\mu^{\alpha_1} + a_2\mu^{\alpha_2})e^{-c\mu^d}$$

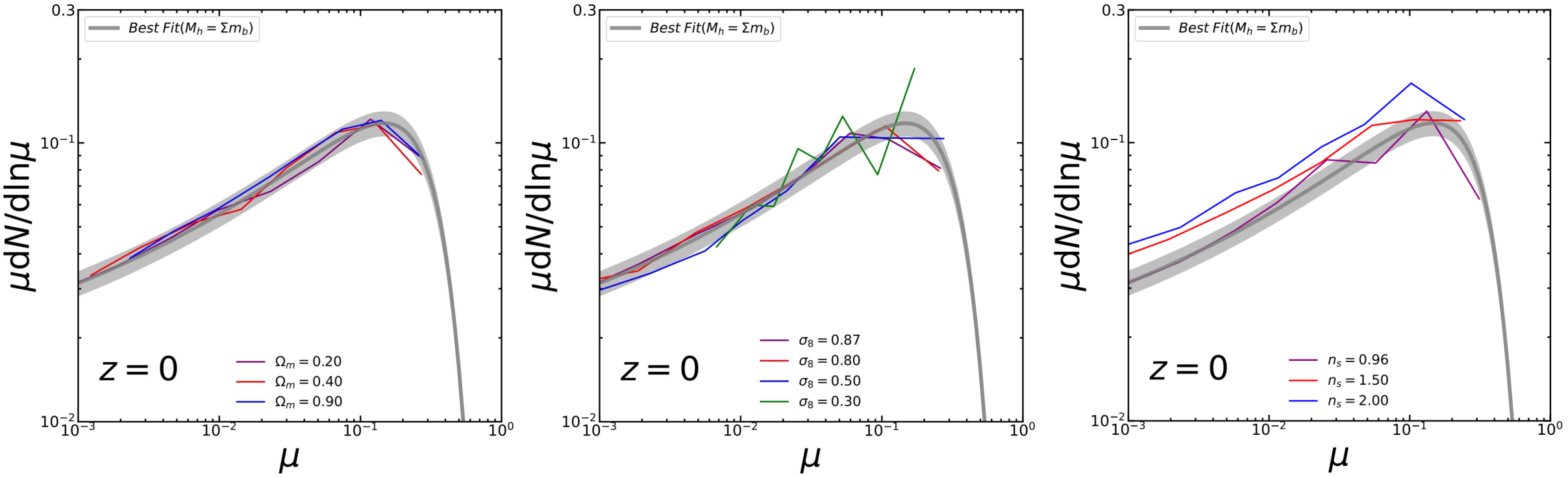


For different M_h, the universality reaches **5%.**



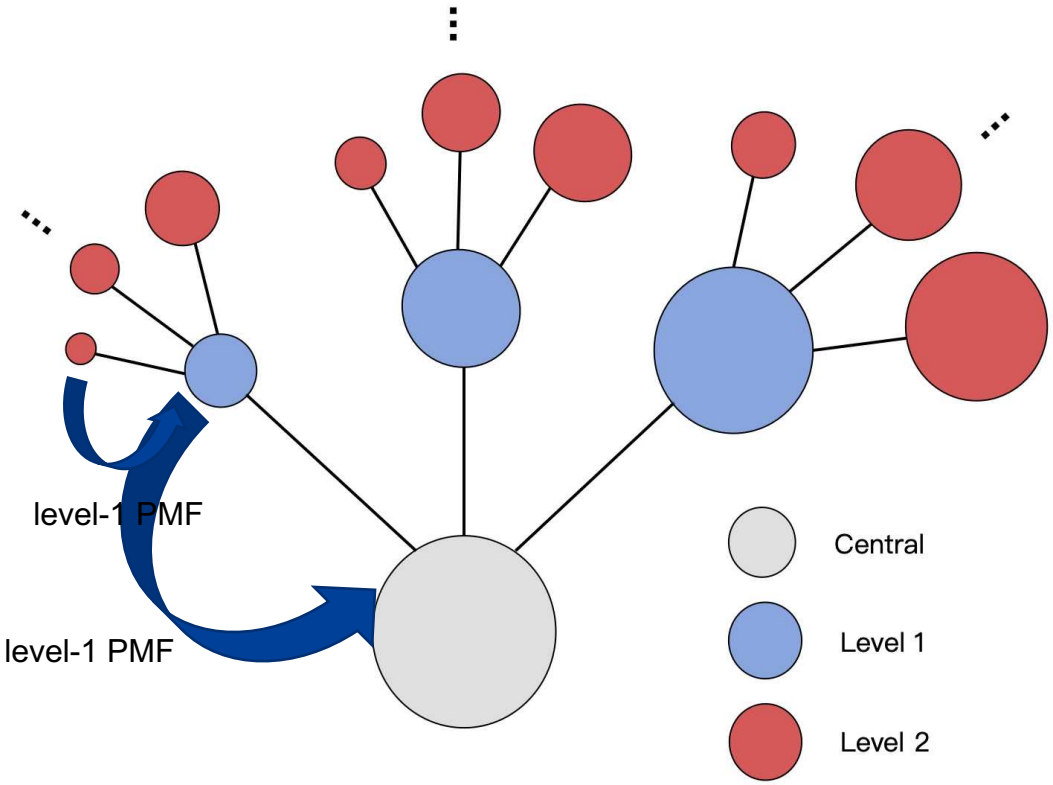
At z=3, the universality can still be preserved within **10%**.

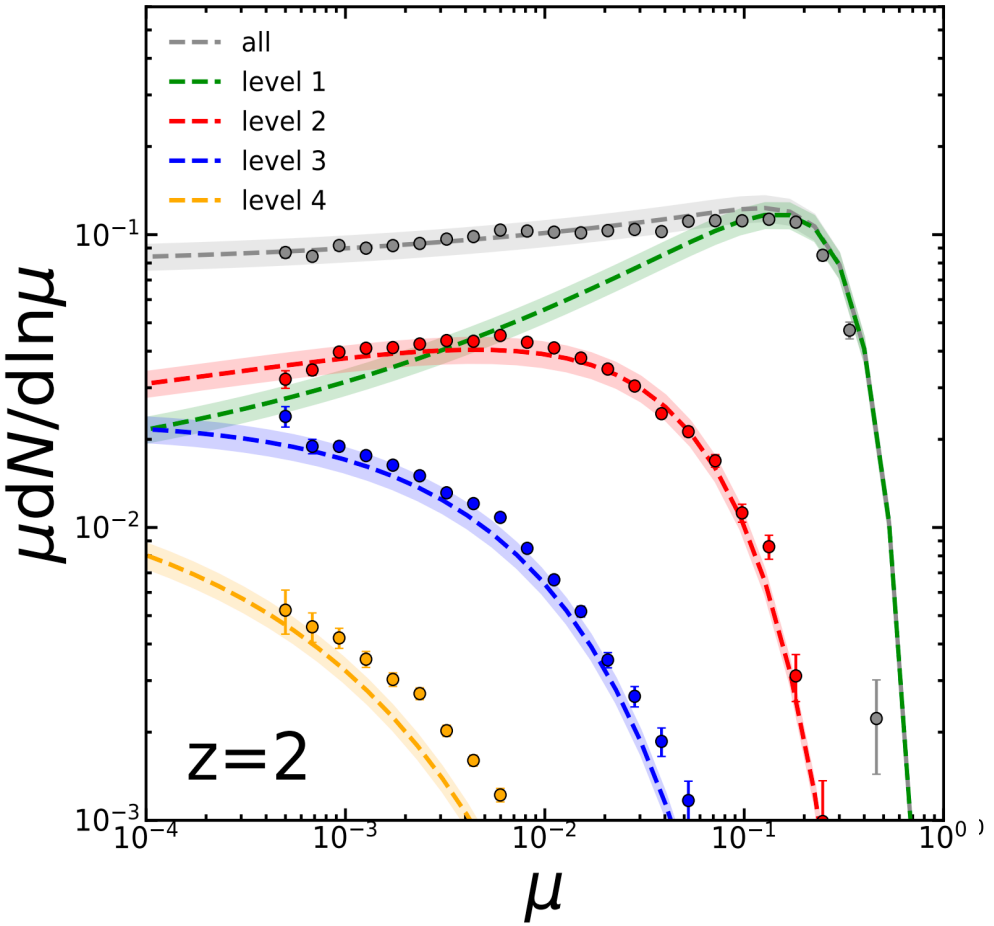
Cosmological Dependence



The universality of the level-1 PMFs can be preserved within **10%** across comologies with different σ_8 and $\Omega_{\rm m}$, but it shows mild dependence on $n_{\rm s}$.

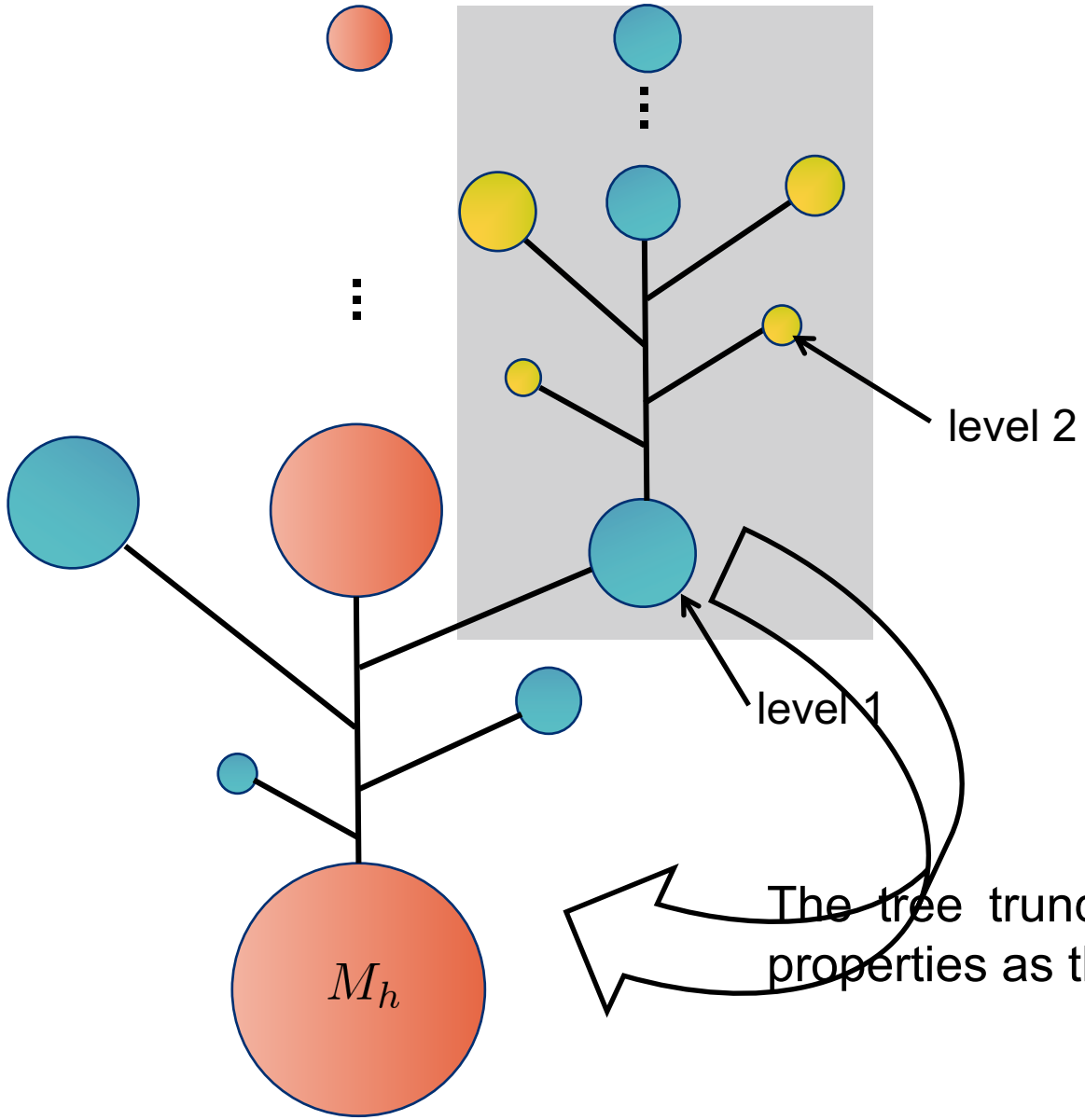
Build up the subhalo hierarchy





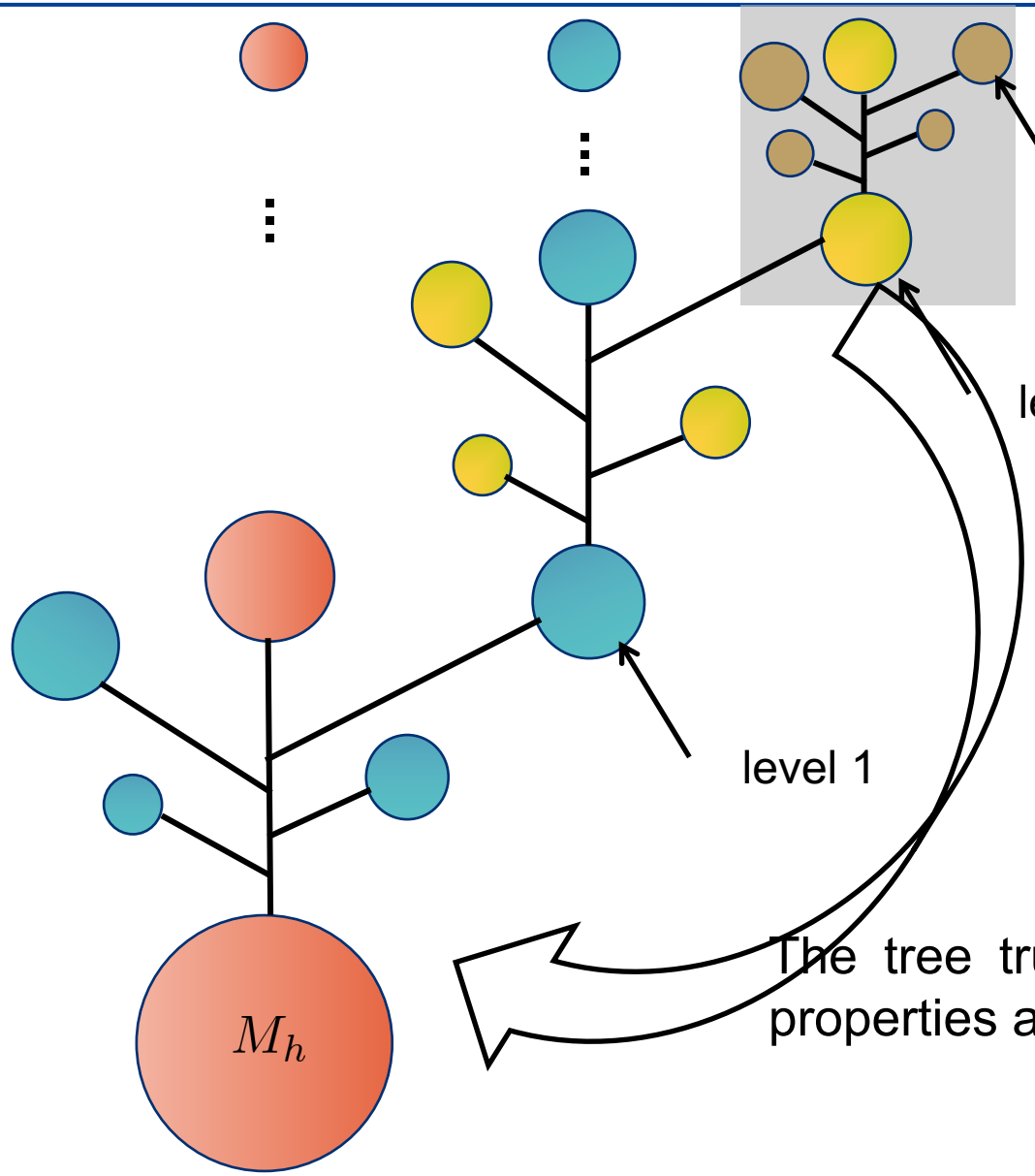
The algorithm can still be presented well with the simulation at $z=0$ ($<10\%$)

Self-Similarity in merger tree



The tree truncated at **any** branch has the **same** branching properties as the root branch.

Self-Similarity in merger tree

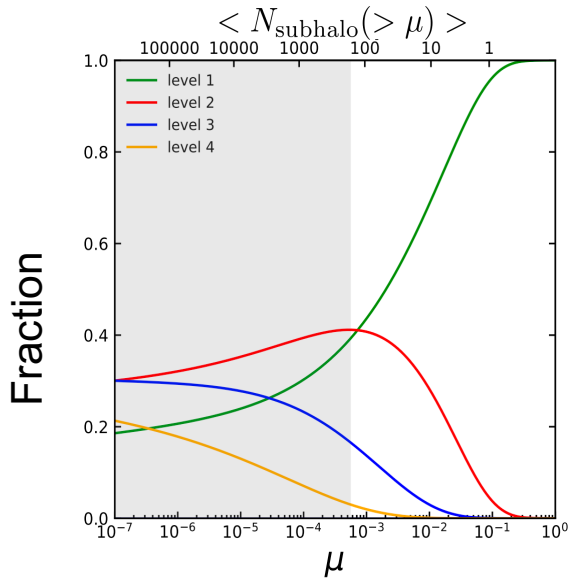


Fractals in nature

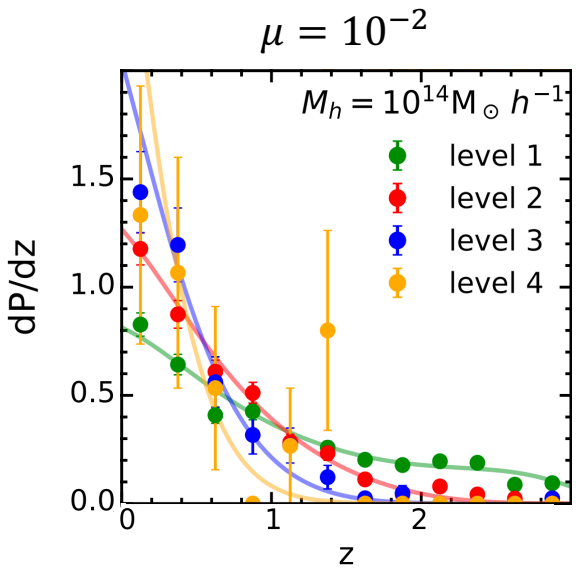
The tree truncated at **any** branch has the **same** branching properties as the root branch.

Model Applications

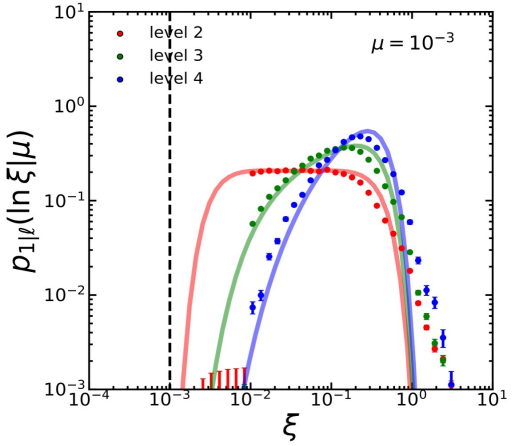
Composition of the subhalo population



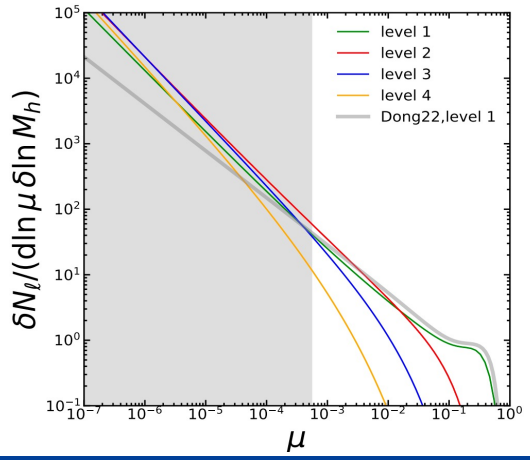
Accretion redshift



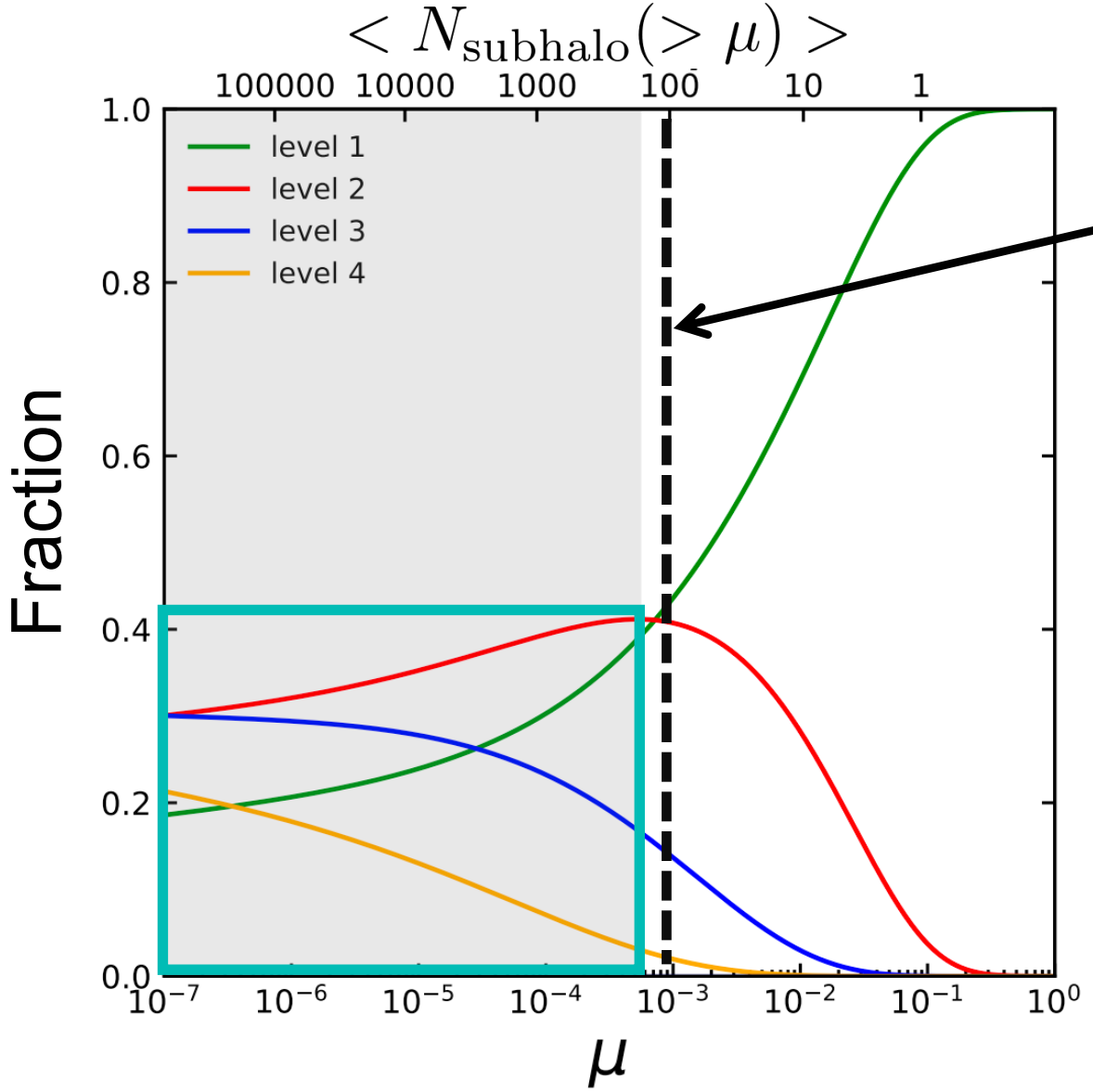
Initial merger ratio



Subhalo accretion rate



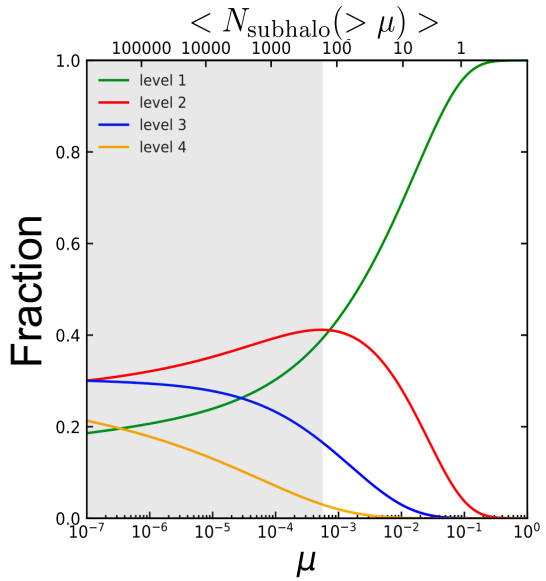
Model Applications



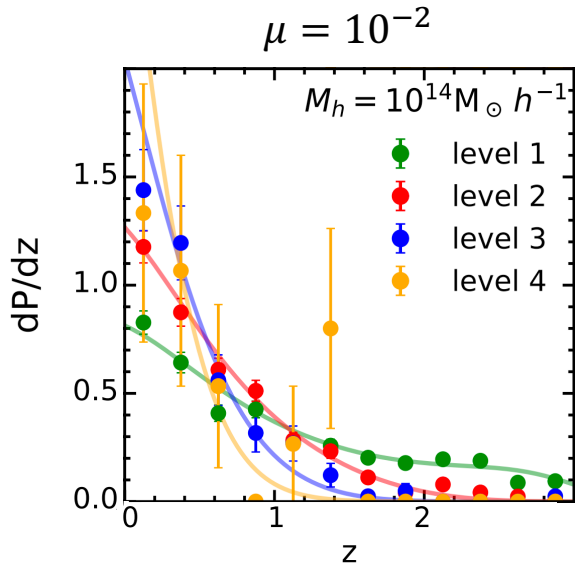
Only **40%** of the top 100 subhalos by mass originate from **direct mergers** with main halos.

The **higher-level** subhalos become more popular with decreasing peak mass ratio.

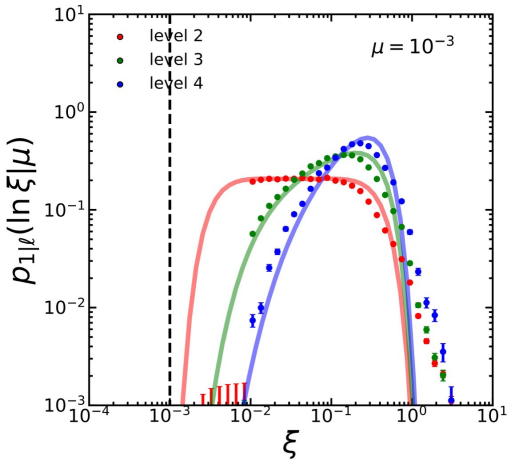
Composition of the subhalo population



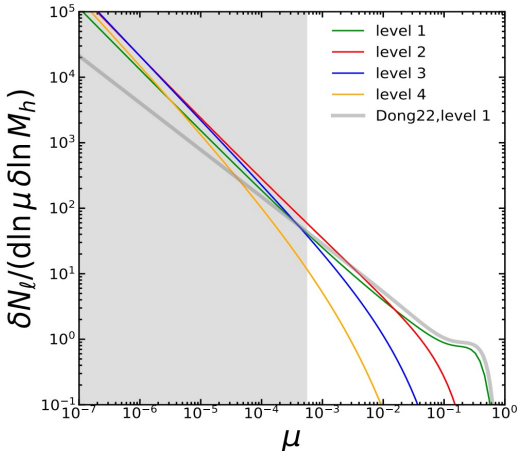
Accretion redshift



Initial merger ratio

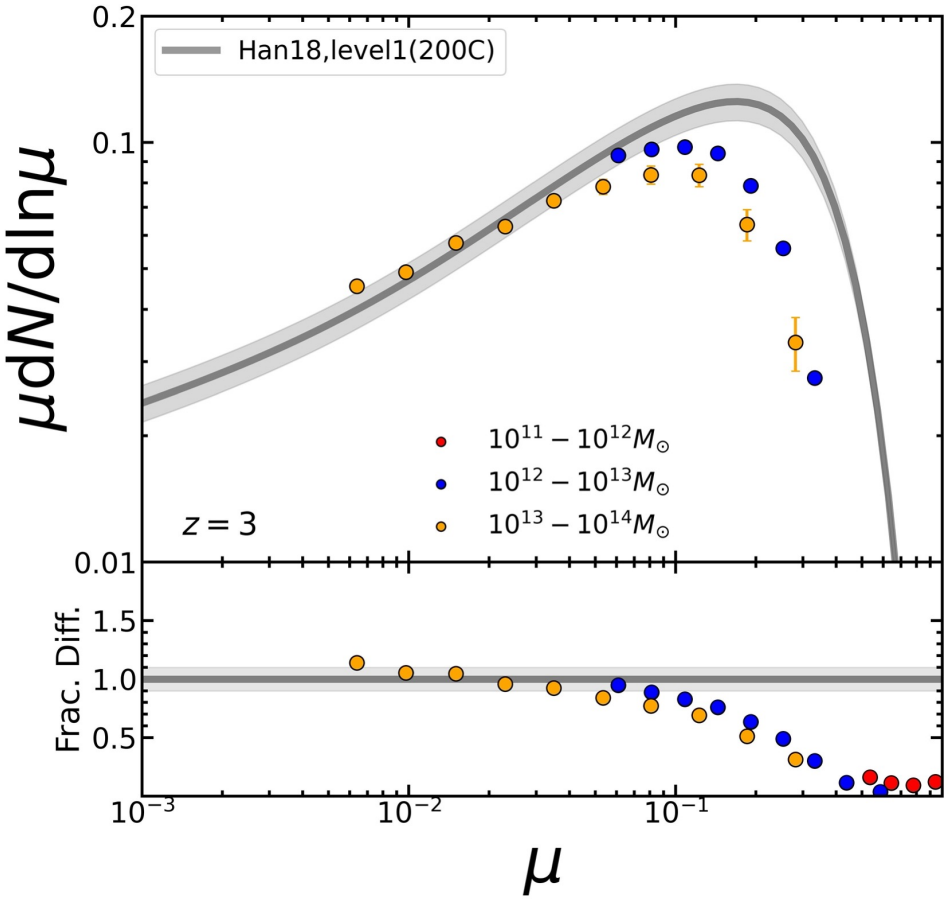


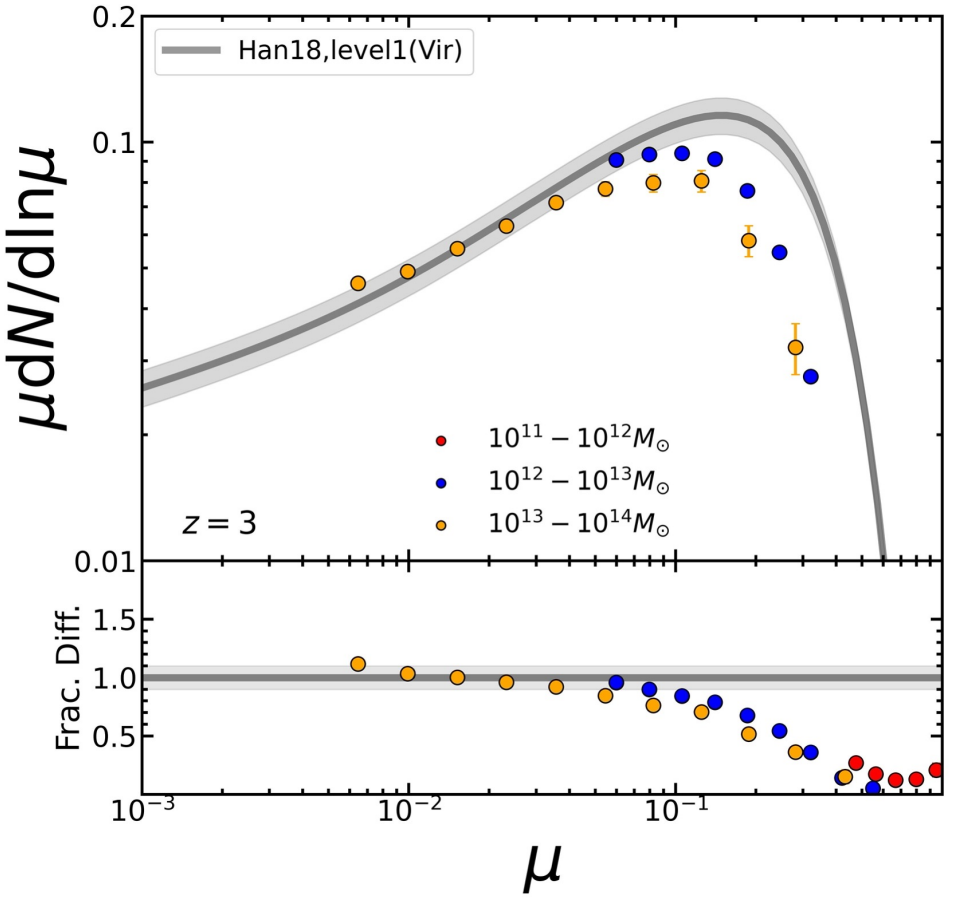
Subhalo accretion rate



- Low-mass subhalos are dominated by **high-level** ones.
- High-level subhalos are built up more **recently**.
- Majority of high-level ones have experienced **major mergers**.
- ...

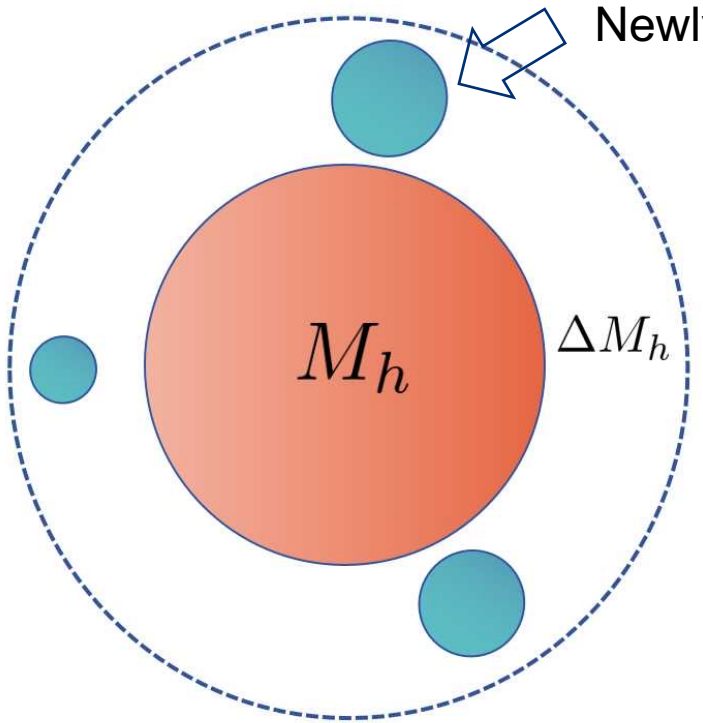
Non-universality from other definitions





The **non-universality** emerges for the halo boundary determined by SO.

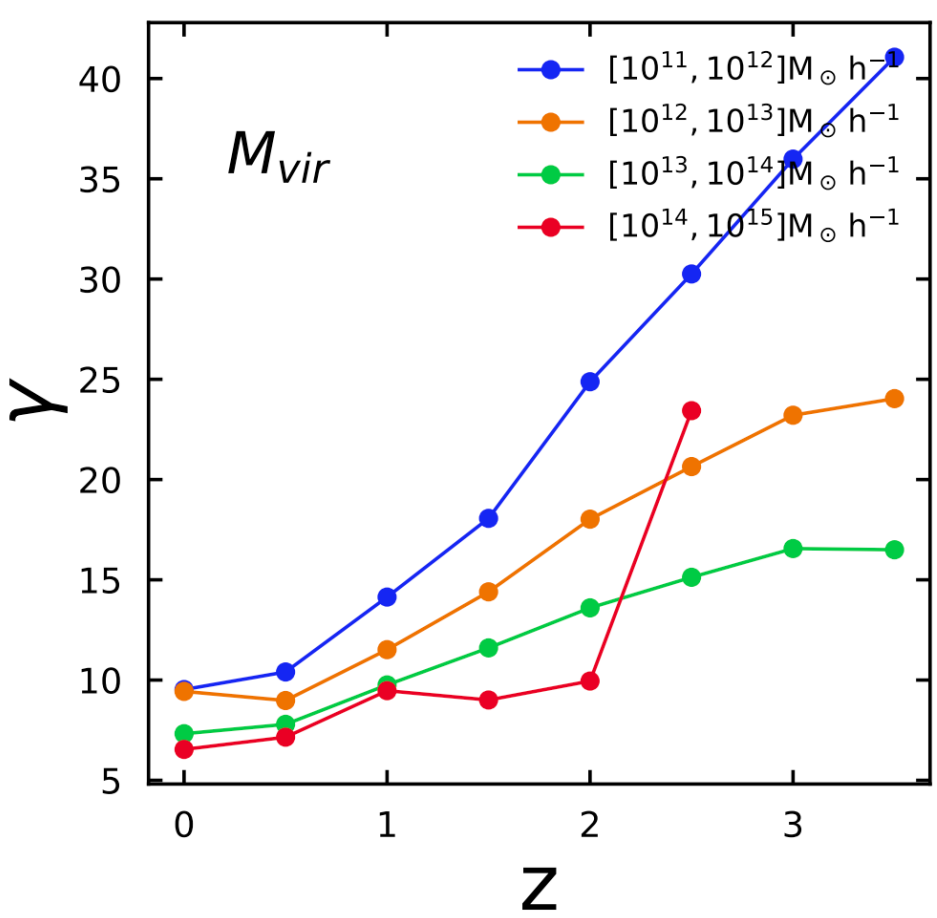
Mass Conservation

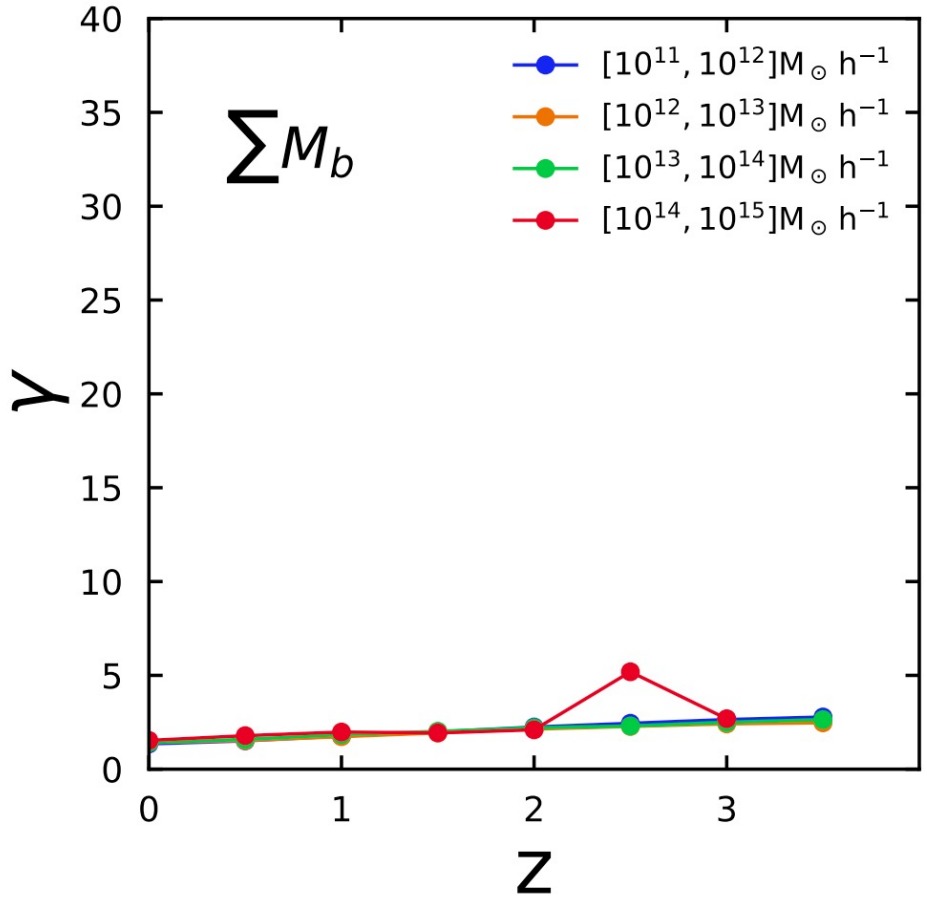


$$\gamma = \frac{\sum m_{peak,i}}{\Delta M_h}$$

The universality implies that gamma must remain **constant** across halos of different M_h and z .

Self-consistent Halo Boundary





The **halo boundary** does not consistently match the **orbital extents** of its member particles.

Summary

- The PMFs across all levels exhibit approximate **universality** and can be obtained analytically via **"convolution"** from the PMFs at the first level. Such universality reveals the fractal structure of the merger tree.

- Using the model, we study subhalo properties across levels: contributions to the total, accretion redshifts, and merger ratios.

- A **physical** definition could potentially provide more self-consistent boundaries for the study of halo mergers.