Increasing a mock's reach with the cosmic web

based on
arXiv:2012.10170

Sujatha Ramakrishnan
with Aseem Paranjape and Ravi Sheth

Cosmology from Home, 2021

IUCAA Pune

Outline

- Introduction:

01:42 Why do we need large volume mock catalog?
02:48 mocks with N-body simulations
03:32 limitations of N-body simulations
08:15 how can the cosmic web help to mitigate the limitations

- Method

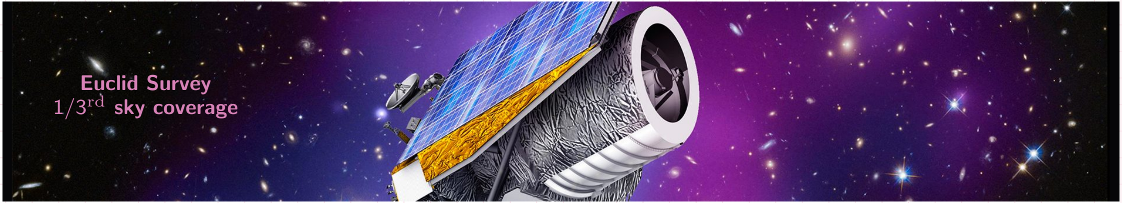
11:42 conditioning on the local cosmic web environment
14:14 description of algorithm

- Results

15:52 Comparing regular simulation with the mocks created with our algorithm.
17:26 Summary

Future Large Sky surveys need large volume mocks

- to compare & connect theory with observations
- to achieve increase in accuracy with increase in precision - cosmological parameter estimation
- N-body numerical techniques

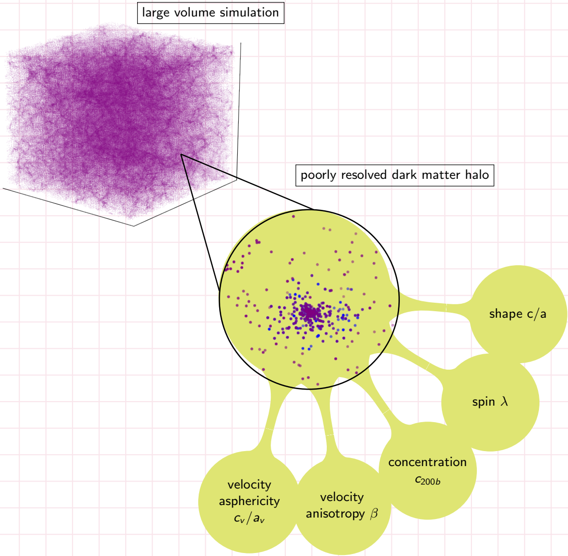


N-body simulations

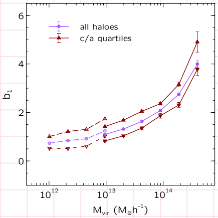
We rely on numerical N-body techniques when

- overdensities much greater than 1
- gravitational collapse becomes non-linear
- analytical approximations no longer valid
- at recent times $z \sim 0$

Limitations



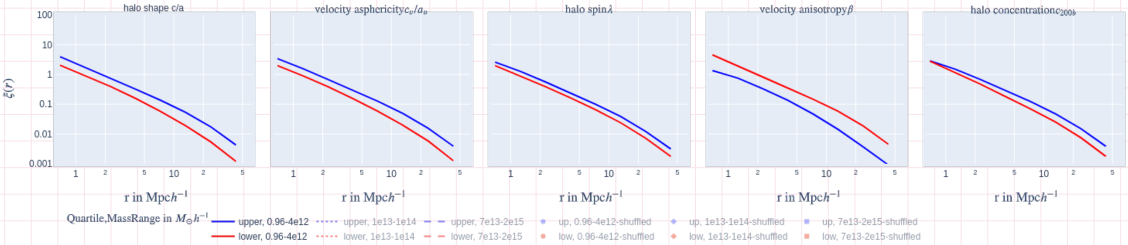
Limitation - Halo assembly bias signal is unresolved



- uncertainities in the 2-pt-correlation function of galaxy clusters
- At fixed halo mass the 2-pt function can be different based on the subsample of properties considered
- this is termed as halo assembly bias
- more commonly dependence of large scale bias

$$b_1 = \frac{P_{\mathrm{hm}}}{P_{\mathrm{mm}}}\bigg|_{k_{\mathrm{small}}}$$

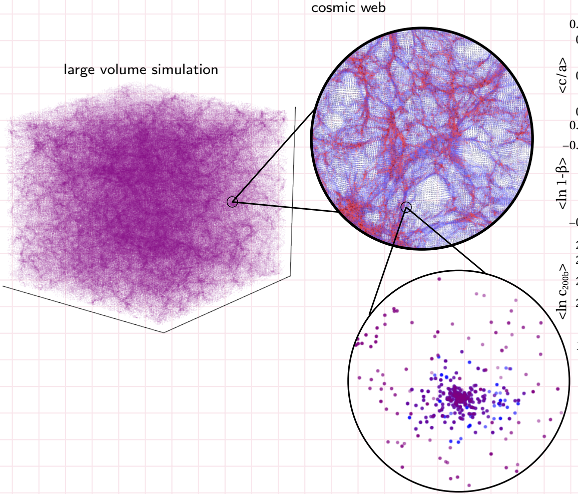
on the beyond mass halo properties is called assembly bias.

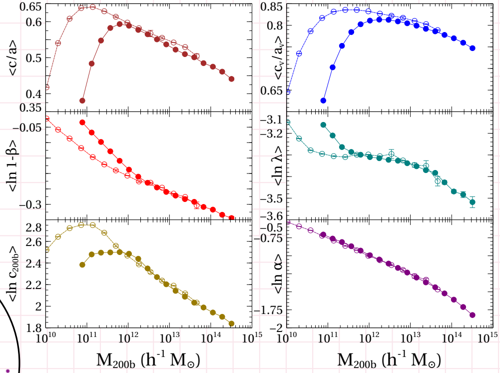


Information in the cosmic web environment

Each halo's environment can be described by the tidal anisotropy $\alpha = \sqrt{\frac{1}{2}\left[(\lambda_2 - \lambda_1)^2 + (\lambda_3 - \lambda_1)^2 + (\lambda_3 - \lambda_2)^2\right]} / (1 + \delta)$

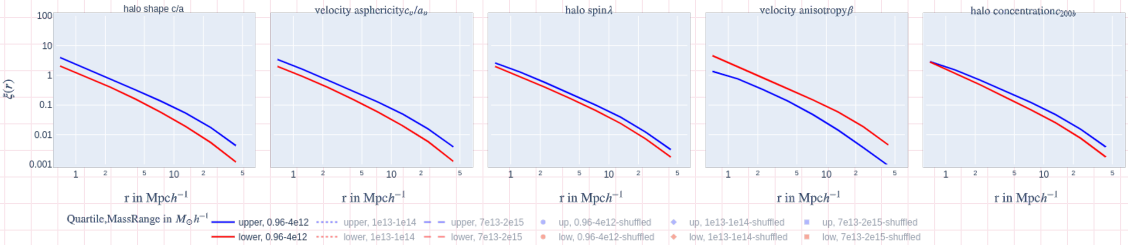
$\lambda_1, \lambda_2, \lambda_3$ are the eigen values of the tidal tensor.



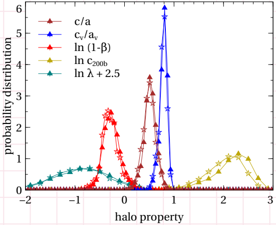


Tidal anisotropy statistically explains halo assembly bias

- no assembly bias for haloes in a fixed tidal anisotropy environment
- For halos with internal property c, mass m and halo bias b_1 the following holds $p(c, b_1|\alpha, m) = p(c|\alpha, m)p(b_1|\alpha, m)$ - Ramakrishnan,et,al 2019
- At fixed halo mass, $b_1 \leftrightarrow \alpha \leftrightarrow c$

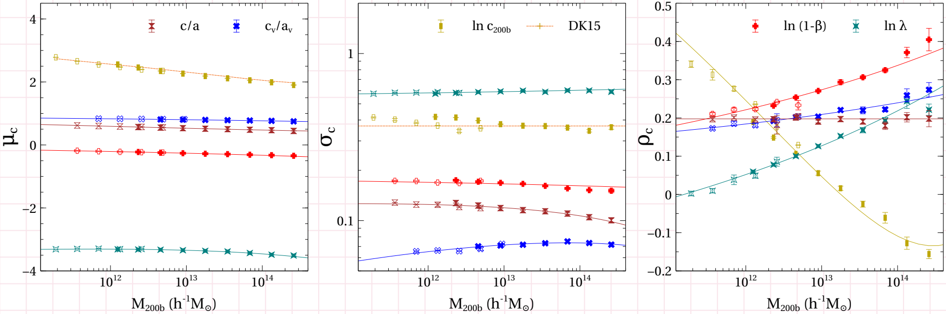


Distribution of c



$$p(c|\alpha, m) = e^{-(c-\rho_c\alpha-\mu_c)^2/2\sigma_c^2(1-\rho_c^2)}$$

μ_c = mean of c , σ_c=standard deviation of c, ρ_c = pearson correlation between α and c.

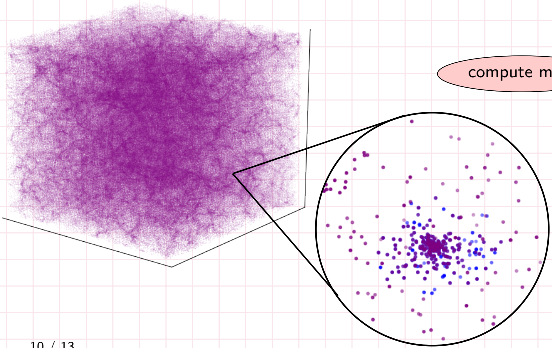


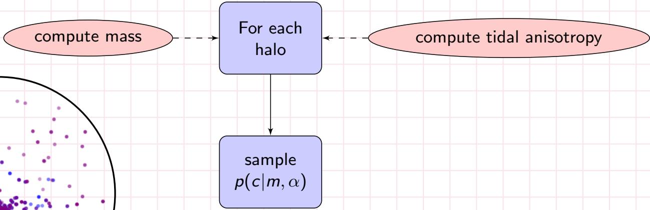
Creating Mock Catalogs :Algorithm

- In low resolution simulations where halo properties are not resolved, we can populate haloes with their internal properties by sampling $p(c|m,\alpha)$
- useful for large volume mock catalogs in large scale surveys

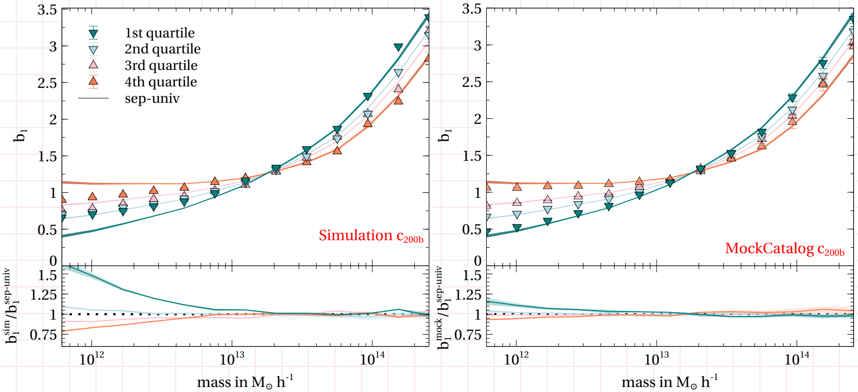
$$p(c|\alpha, m) = e^{-(c-\rho_c\alpha-\mu_c)^2/2\sigma_c^2(1-\rho_c^2)}$$

μ_c = mean of c , σ_c=standard deviation of c, ρ_c = pearson correlation between α and c.

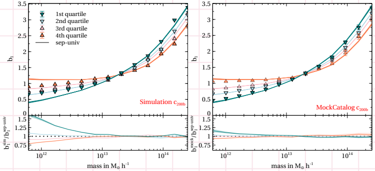


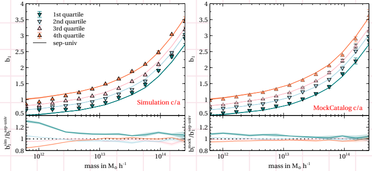


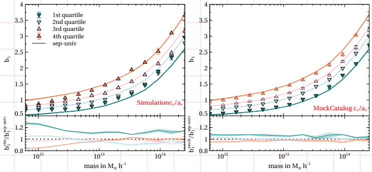
Results

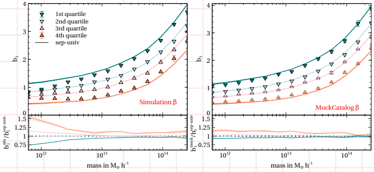


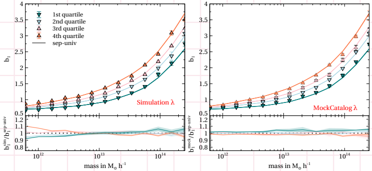
1st quartile
2nd quartile
3rd quartile
4th quartile
sep-univ
Simulation c_{200b}
MockCatalog c_{200b}
b_1
$b_1^{sim}/b_1^{sep\text{-}univ}$
$b_1^{mock}/b_1^{sep\text{-}univ}$
mass in $M_\odot\ h^{-1}$











Note: We do not use any information about $c \leftrightarrow b_1$ for sampling the mocks but retrieve $c \leftrightarrow b_1$ naturally.

Summary

- The tidal anisotropy around a halo is the primary driver of the halo assembly bias. As a proof-of-concept we show the two point correlation of a sample of shuffled halo properties retains the same strength as an unshuffled version.
- Tidal anisotropy is well resolved for haloes whose particle count is between 30-700, where the internal properties are not resolved.
- We develop an algorithm that uses the tidal anisotropy and mass to assign mock halo properties to these unresolved haloes.
- Our algorithm
    - increases a simulation's reach in halo mass and number density by an order of magnitude.
    - improves bias signal by percentages as large as 45% for the 30 particle haloes.
    - can possibly incorporate assembly bias in fast aproximate simulations.