Dark Matter Halo Mass Correction in Mock Universe Simulations

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Introduction/Motivation:

- Widespread Homogeneity to Cosmic Webs
  - Unknown as to how transition happened
- Simulations can help
- Full Physics Simulation (FPS) vs. Dark Matter Only Simulations (DMOS)
- Full physics is a lot….but just gravity?

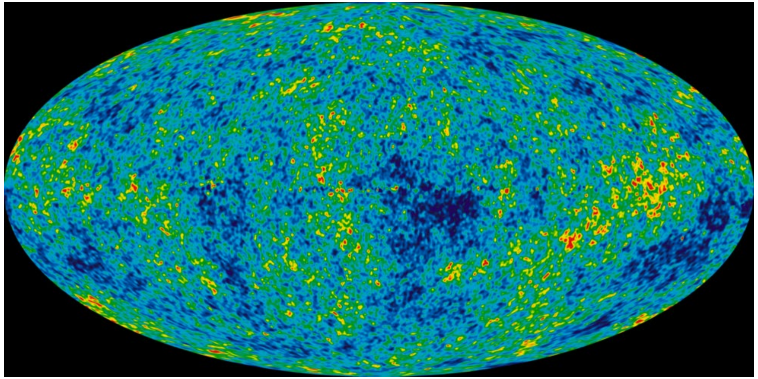


Image provided by NASA: Wilkinson Microwave Anisotropy Probe June 28, 2016

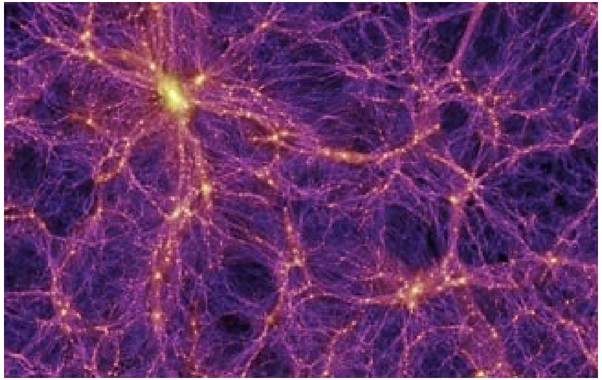


Image provided by Millennium Simulation Project; Springel V., et al

Motivating Literature

- Based on one of the five papers produced from IllustrisTNG project
  - "First Results from the IllustrisTNG simulations: Matter and Galaxy Clustering" (Springel, V. et al., **Monthly Notices of the Royal Astronomical Society, Volume 475, pg 676-698,** (2017))
- IllustrisTNG: Successor to the pre-existing Illustris Suite
  - Larger (TNG300) Higher Resolution (TNG50) Updated Cosmology (TNG100)
  - Each FPS has an identical DMOS counterpart
- Results: FPS Strongly Correspond to Extant Observations

Theory

- IllustrisTNG FPS shown to be successful
- DMOS shown to be systematically skewed
- Systematic Correction — Given DMOS results, can we reconstruct FPS results?
  - Plot FPS v. DMOS
  - Assume a map $f: F \to D$ with inverse $f^{-1}: D \to F$
  - Find transformation s.t. ∃ map $g: D \to D' = F$
  - Assessment: Direct Comparison
- Apply to other simulations
  - AbacusSummit (DMOS designed to meet cosmological requirements of Dark Energy Spectroscopic Instrument (DESI) Survey)
  - Apply found transformation
  - Assessment: Find Correlation Function* ($\xi(r)$) before and after transformation

*Correlation Function: "Given a galaxy of mass *M,* what's the probability of finding another galaxy a distance *r* away?"

Methods

IllustrisTNG

- To construct sought after map, we plot relevant data points on an FPS v. DMOS scatter plot
- Find line of best fit
- Mix of linear algebra and trigonometry to correct trend
  - Full Rotation
  - DMOS Rotation
  - Drop Method

AbacusSummit:

- Apply Correction Methods
- Halo Occupancy Distribution (HOD) module

Data Collection/Analysis

- Both Simulations provided data via website or Globus file transfer site
- Same Cosmologies; Planck 2018 ΛCDM
- Same Red-Shift; $z = 0.1$ ($z = 0$ would be present day)
- Analysis done using Python modules produced by IllustrisTNG team and AbacusSummit Team
  - IllustrisTNG:
    - subhalo_matching_to_dark.py is used to assign each FPS subhalo to a corresponding DMOS subhalo with similar properties
  - AbacusSummit:
    - AbacusHOD module is used to imbed baryonic matter in DMOS results
    - NOT a DMOS to FPS conversion
    - "Given this distribution of dark matter halos, we expect baryonic matter to be distributed in these places"

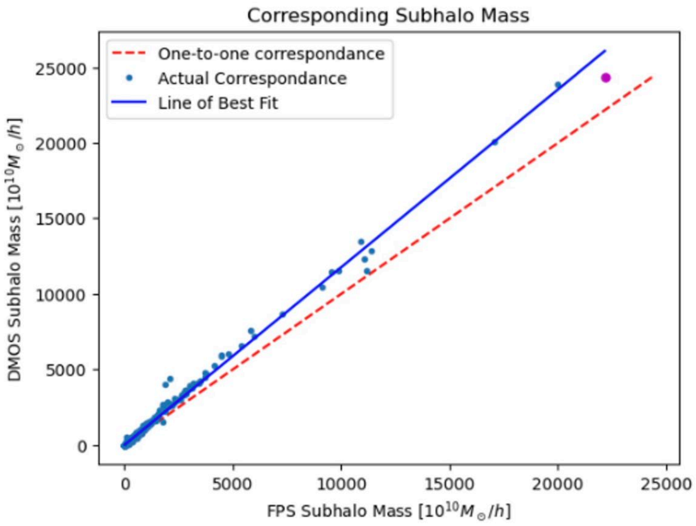
Results: IllustrisTNG

- Full Rotation

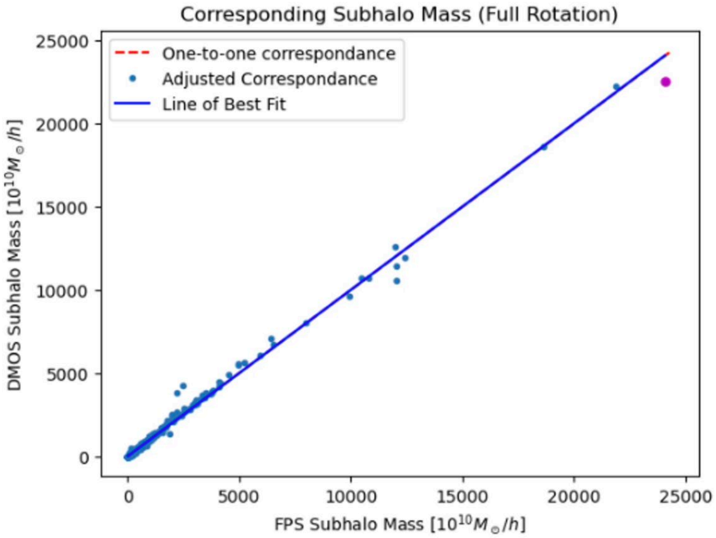
$$\begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix}$$

Where $\theta = \arctan(a) - \frac{\pi}{4}$

(a is slope of best fit)



Slope of best fit is: 1.1767447695373274



Slope of best fit is: 1.00051178119992

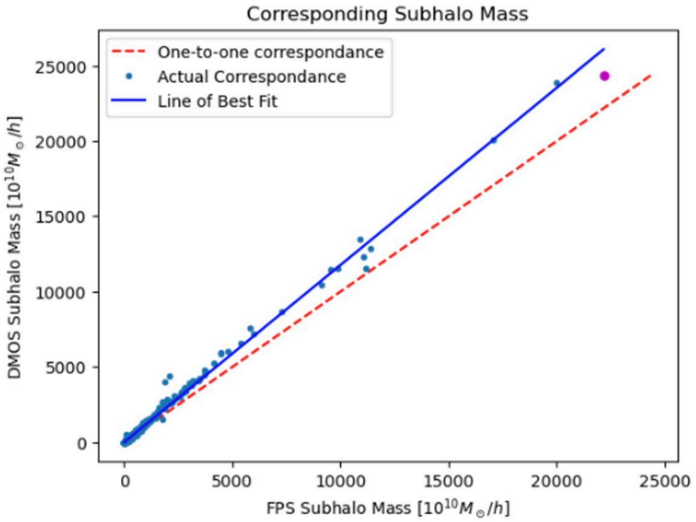
Source: Plots made by Weston Schwartz

Results: IllustrisTNG (Cont.)

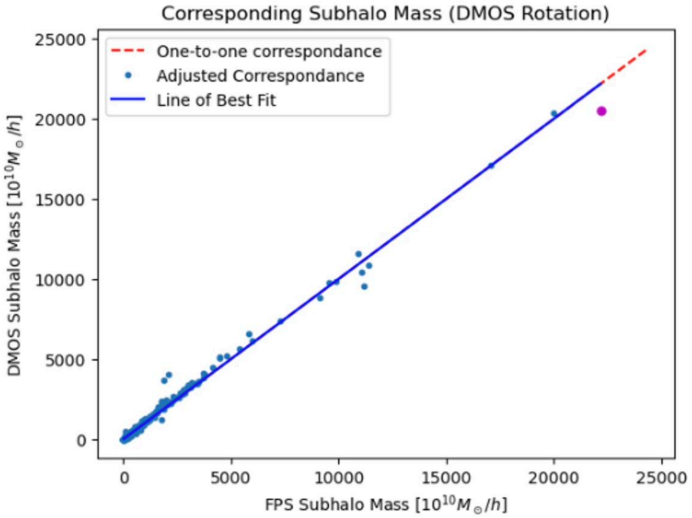
- DMOS Rotation:

$$\begin{bmatrix} 1 & 0 \\ -\sin(2\theta) & \cos(2\theta) \end{bmatrix}$$

Where $\theta = \arctan(a) - \frac{\pi}{4}$



Slope of best fit is: 1.1767447695373274



Slope of best fit is: 1.0000000000000326

Source: Plots and matrix made by Weston Schwartz

Results: IllustrisTNG (Cont.)

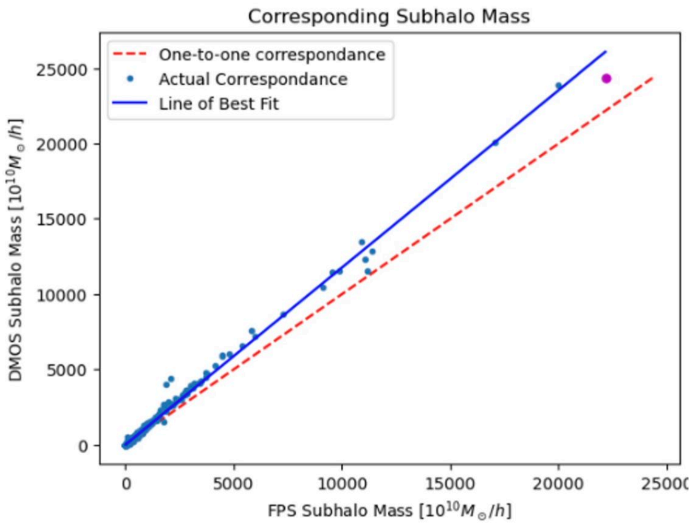
$$drop = \sqrt{3F^2 + D^2 - 2FC\cos(\theta)}$$

Where $C^2 = F^2 + D^2$,

F = FPS Data Point,

and D = DMOS Data Point

- Drop Method



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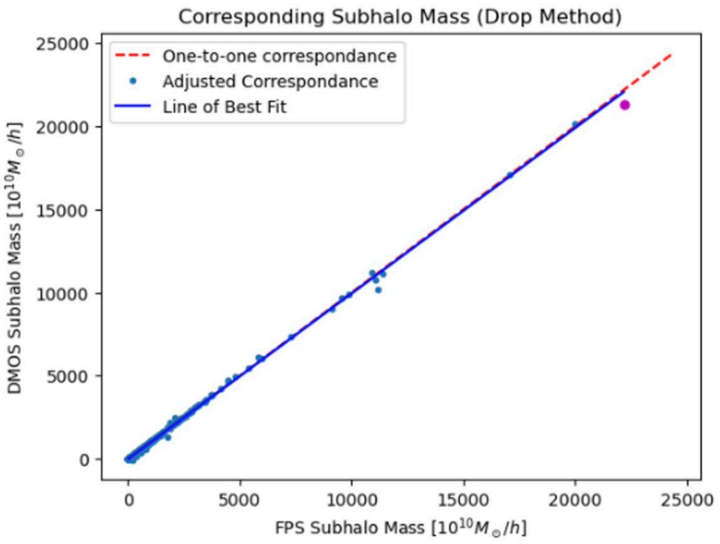


Slope of best fit is: 0.9947288710009976

Source: Plots and eq. made by Weston Schwartz

Results: Correcting the Correction

- Realized these correction methods are still dependent on FPS data
- Had to reformulate:

$$drop = D - D\sqrt{\frac{1-\sin(2\theta)}{1+\sin(2\theta)}}$$

Where D is a Data Point and $\theta = \tan^{-1}(slope)$ - $\frac{\pi}{4}$

$$D' = D\left[\cos(2\theta) - \sqrt{\frac{\sin^2(2\theta)-\sin^3(2\theta)}{1+\sin(2\theta)}}\right]$$

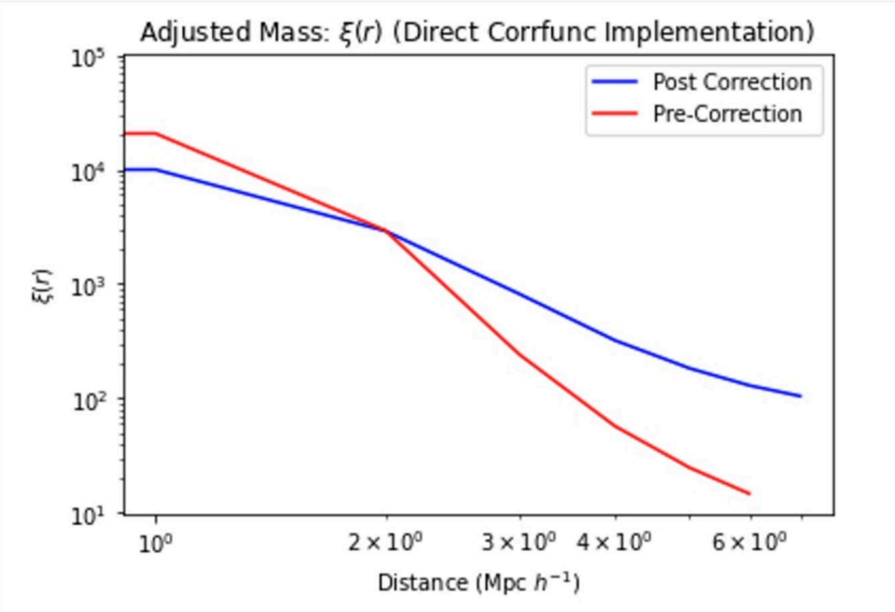
Equations by Weston Schwartz

Results: AbacusSummit

- Without Correction:
  - Over estimated number of pairs are small distances
  - Underestimated for larger distances

- With Correction:
  - More Gradual Descent
  - Follows a quasi-power law
  - Corresponds to IllustrisTNG results

Found, on average, DMOS produces halo masses ~15% higher than FPS



Discussion/Future Work

- Novel methods of correcting halo masses seem to be successful for simulations using Planck 2018 ΛCDM cosmologies at redshift $z = 0.1$
- Correction methods applied to DMOS and then were ran through HOD module
- Apply correction method to HOD module itself (?)

<u>Future Work</u>

- Determining the θ dependence for the correction function
- Generalize this method
- Find Corrections for other halo variables (position, velocity, luminosity, etc.)

Conclusion

- Mock Universe Simulations:
  - Invaluable to understanding large scale structure formation
  - Helps understand overall structure of the Universe
  - Dark Matter
- Successful FPS reproduction via modified DMOS data
- Modification methods offers possibility of optimizing modules such as AbacusHOD
- More efficient Mock Universe Simulations

Acknowledgements

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Questions?