Can cosmological simulations of νHDM ease the large-scale tensions in cosmology?

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40 years of MOND

a_0

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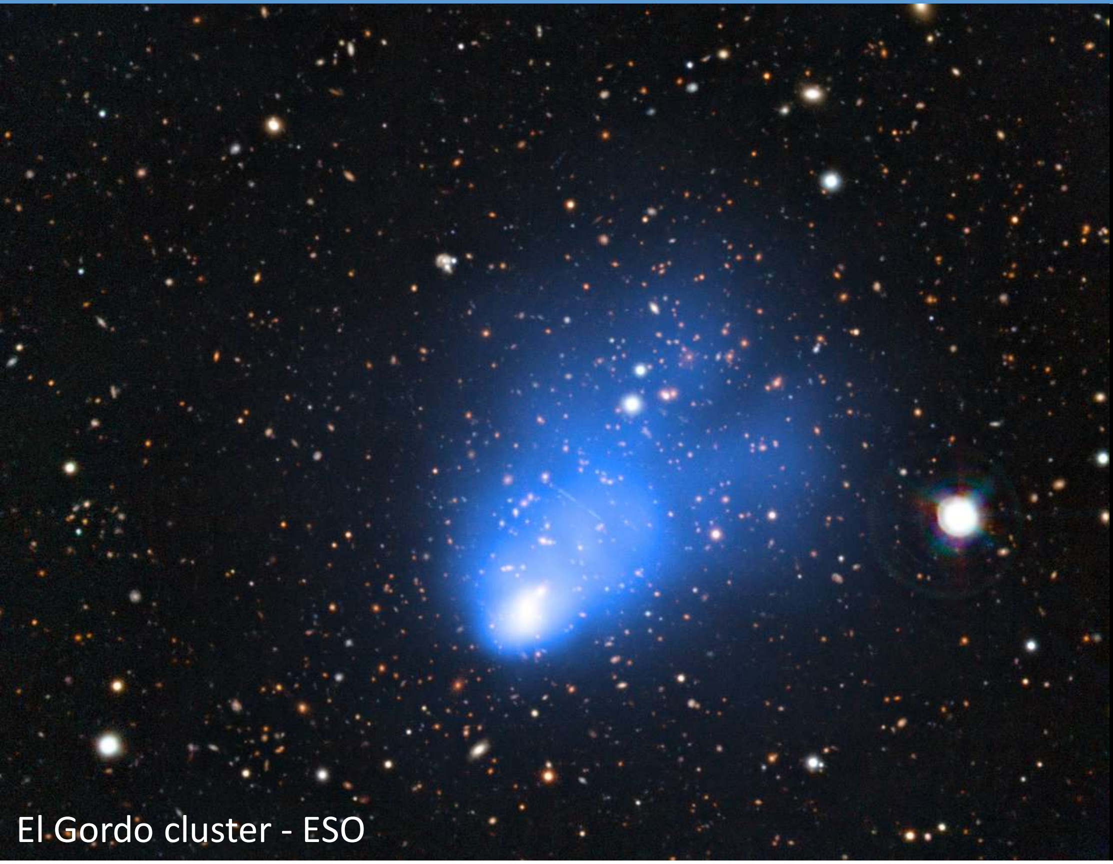
Introduction

- Motivation for a new cosmological model
- Overview of the νHDM model
- My Simulations
- Preliminary results

Motivation: Cracks in the Cosmological Model

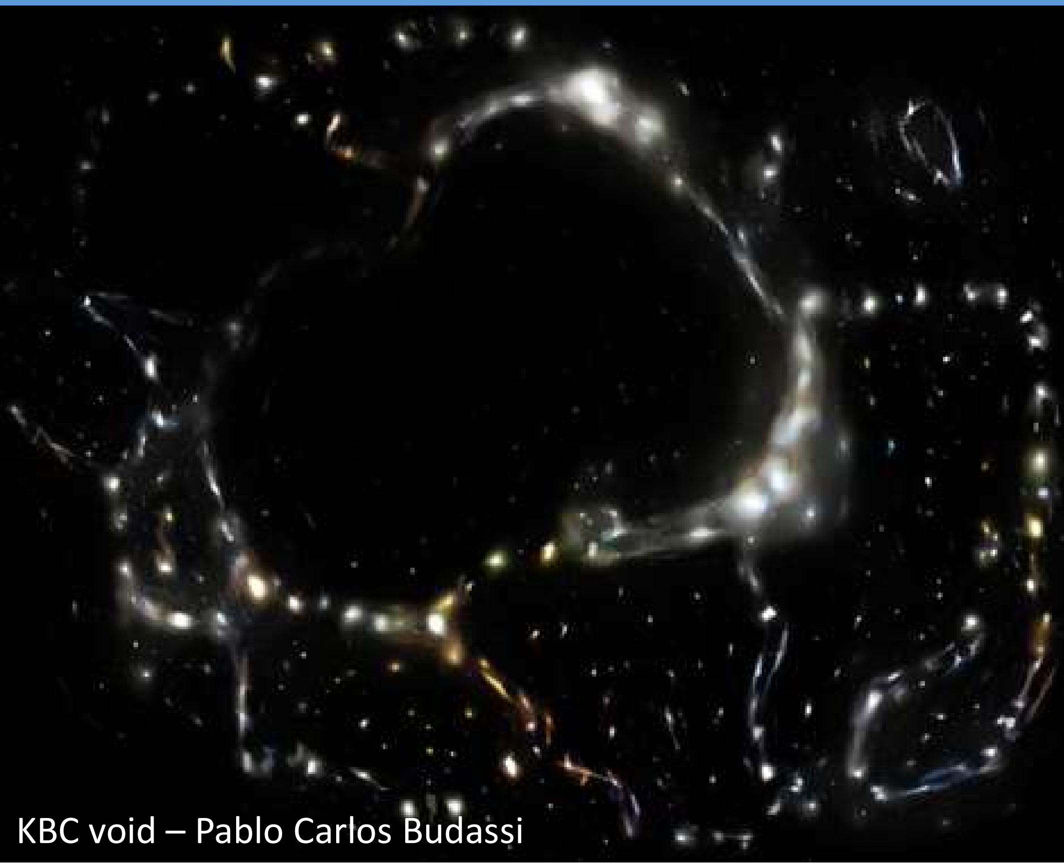


El Gordo cluster - ESO

Enhanced early structure formation

- High local bulk flows
- High velocity cluster mergers
- Fast growing super massive black holes
- High redshift galaxies

Motivation: Cracks in the Cosmological Model



KBC void – Pablo Carlos Budassi

Supervoids on 100s Mpc scales

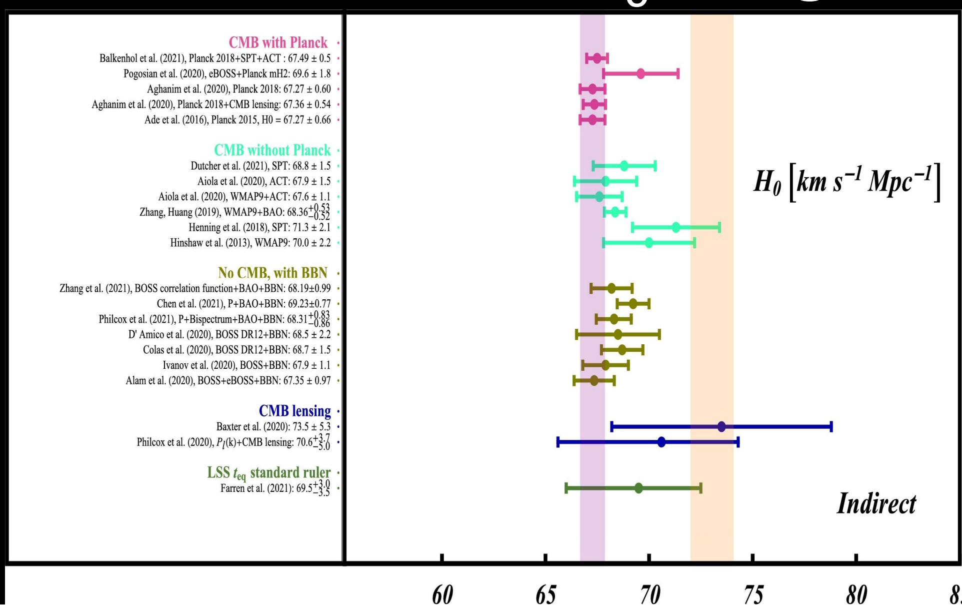
- “Local Hole” with 120 Mpc radius observed in near-IR, X-ray and radio
- Overproduction of ~100 Mpc inferred from Integrated Sachs-Wolfe effect

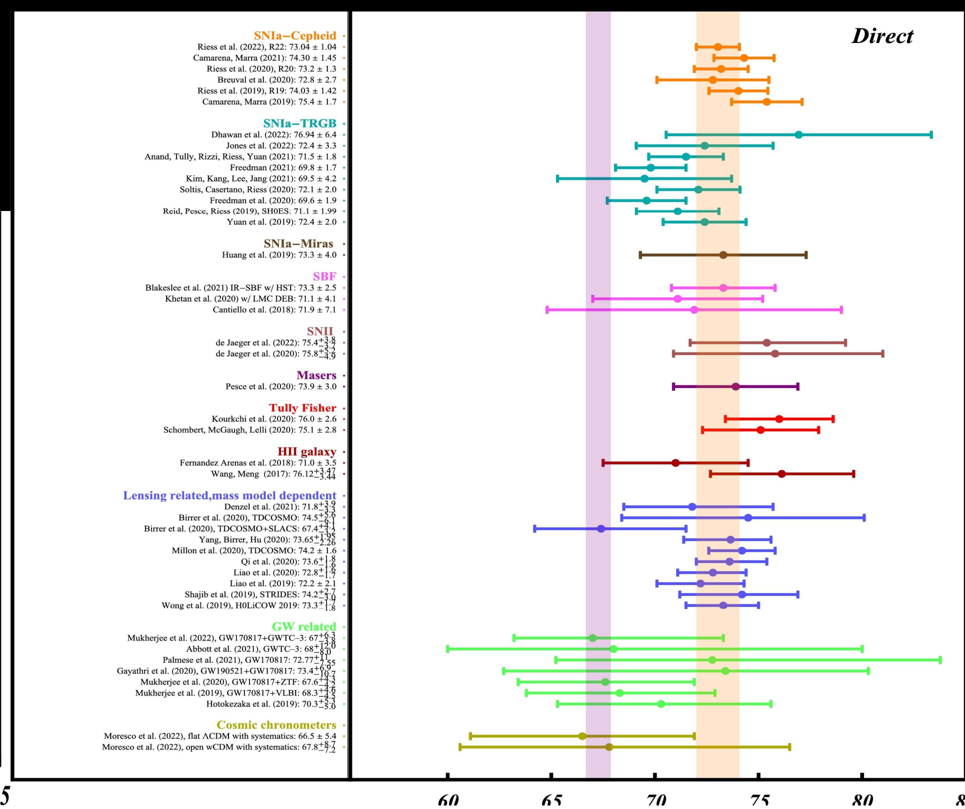
Motivation: Cracks in the Cosmological Model

The Hubble Tension

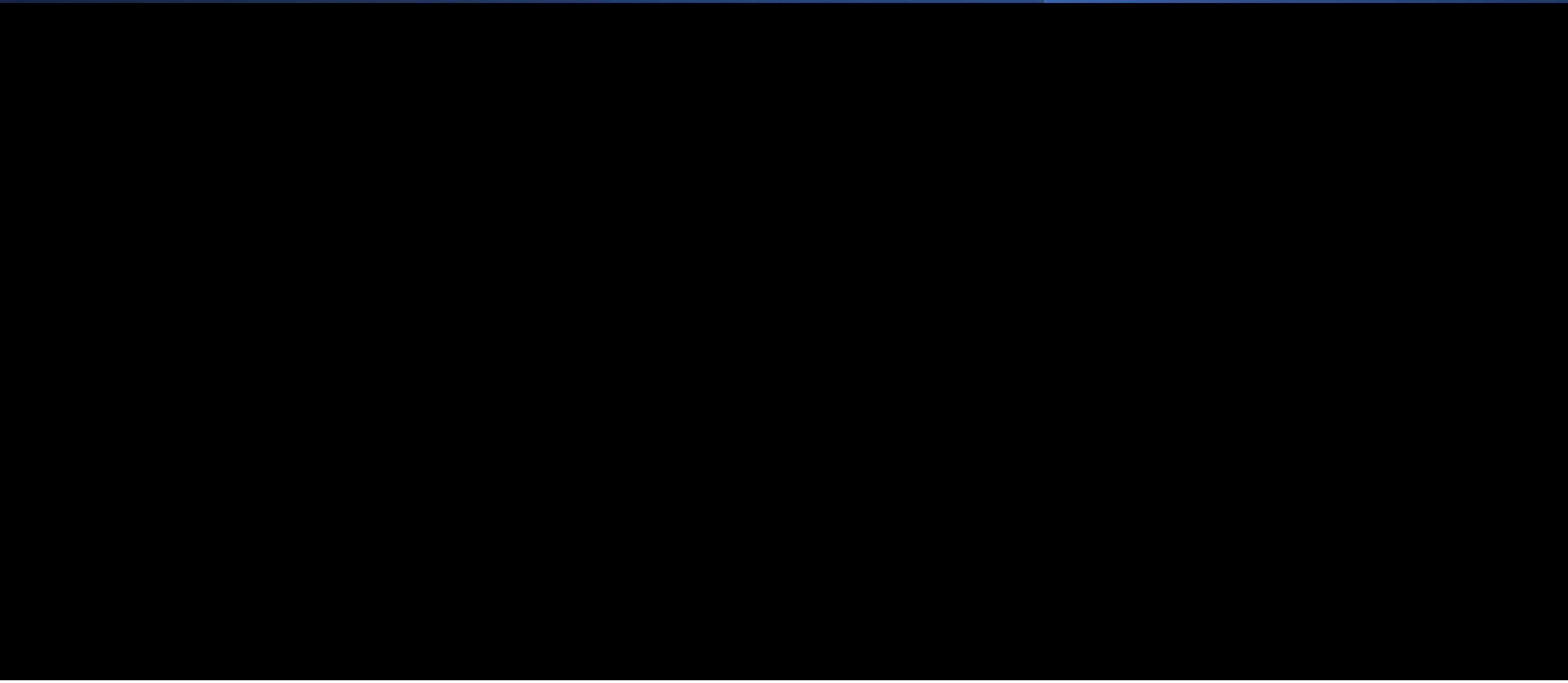
- Early-time and late-time measurements of H_0 disagree!

Abdalla et al. 2022





What is vHDM?



What is ν?

ν is MOND!!!

Simple Interpolation function

$$\nu(y) = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{1}{y}}$$

What is HDM?

HDM is Hot Dark Matter

- Hot Dark Matter particles have low mass and high thermal velocities at recombination

- Free-streaming suppresses small-scale structure

- 11 eV Sterile Neutrinos in νHDM (Angus 2009)

Key assumptions

Assume ΛCDM interpretation of Cosmic Microwave Background temperature anisotropies is (mostly) correct

Assume all Dark Matter is 11 eV sterile neutrinos

Assume background FRLW metric

Assume MOND effects are negligible in the early Universe

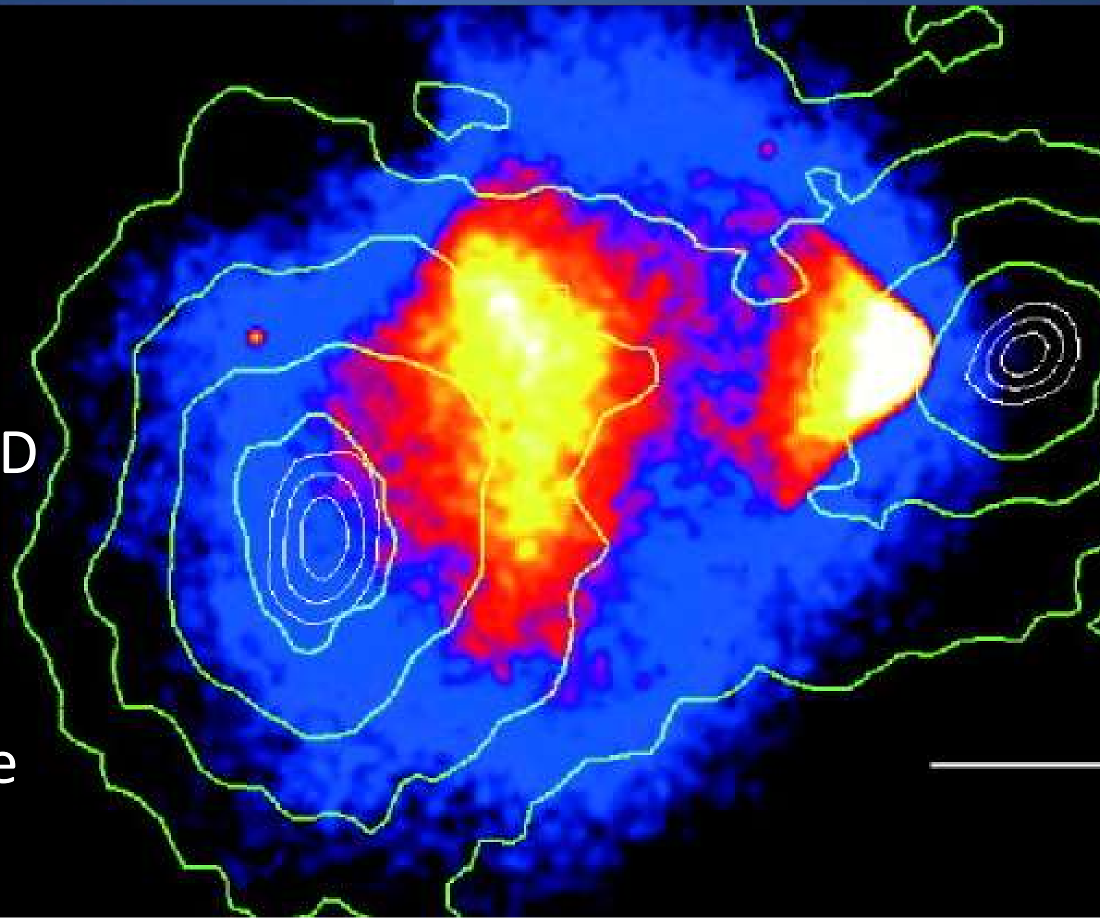
Why combine MOND and Dark Matter?

•HDM means galaxies are purely baryonic and MONDian

• Dark Matter in clusters should ease large-scale issues faced by MOND

• CMB is easily explained

• Stronger MOND gravity will enhance structure formation



Why return to this model now?

- Angus et al. 2013 produced Local Hole analogues **before** it was observed
- A local void solution to the Hubble Tension is possible (Haslbauer et al. 2020)
- The rate of El Gordo analogues in Katz et al. 2013 is observationally accurate (Asencio et al. 2021)

My Simulations

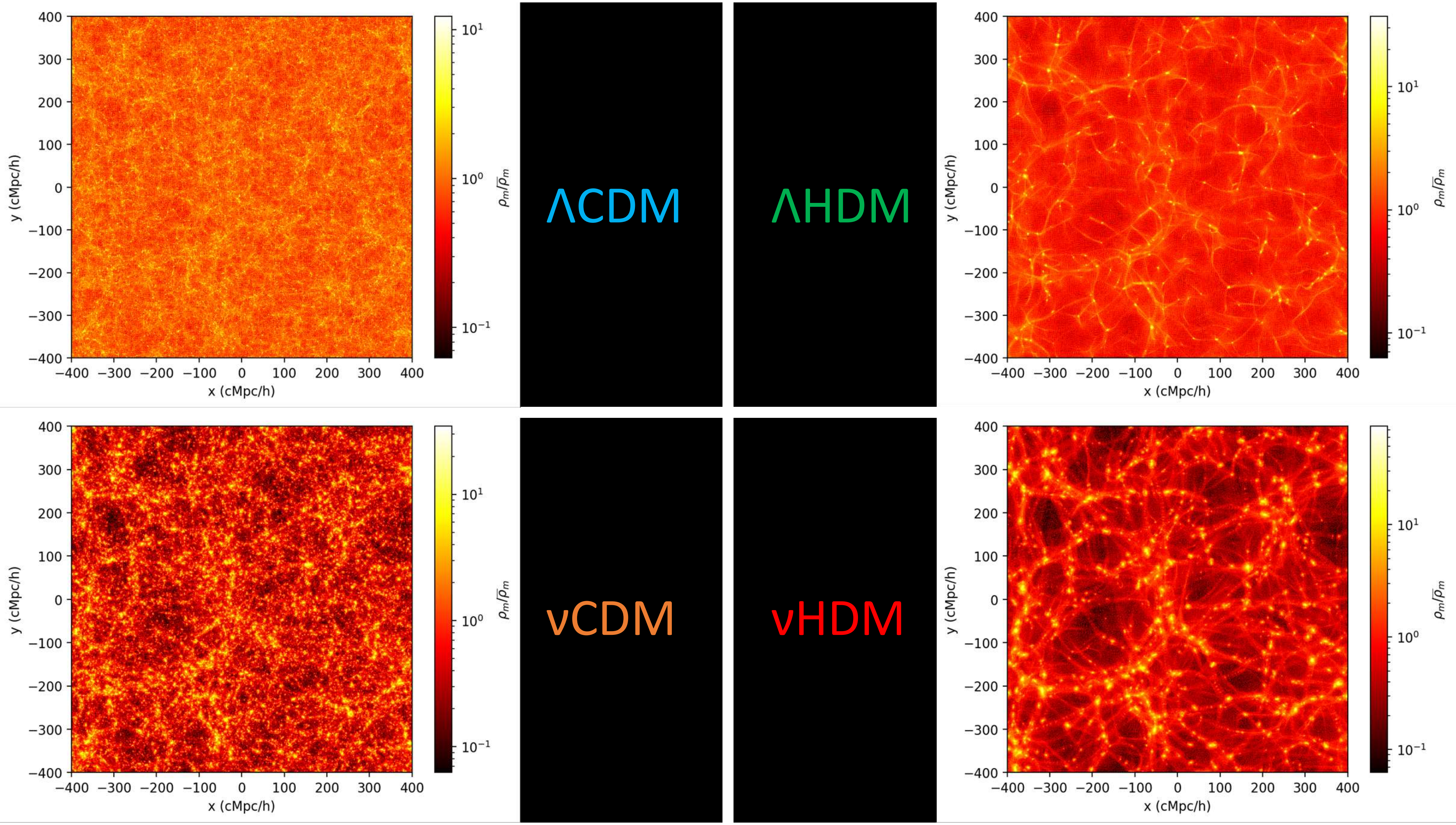
Cosmological collisionless N-body simulations using “Phantom of Ramses” code (Teyssier 2002; Lüghausen 2014)

$$\nabla^2\Phi(\boldsymbol{r}) = 4\pi G\rho(\boldsymbol{r}) + \nabla\cdot\left[\tilde{\nu}\left(\frac{|\nabla\Phi_N|}{a_0}\right)\nabla\Phi_N(\boldsymbol{r})\right]$$

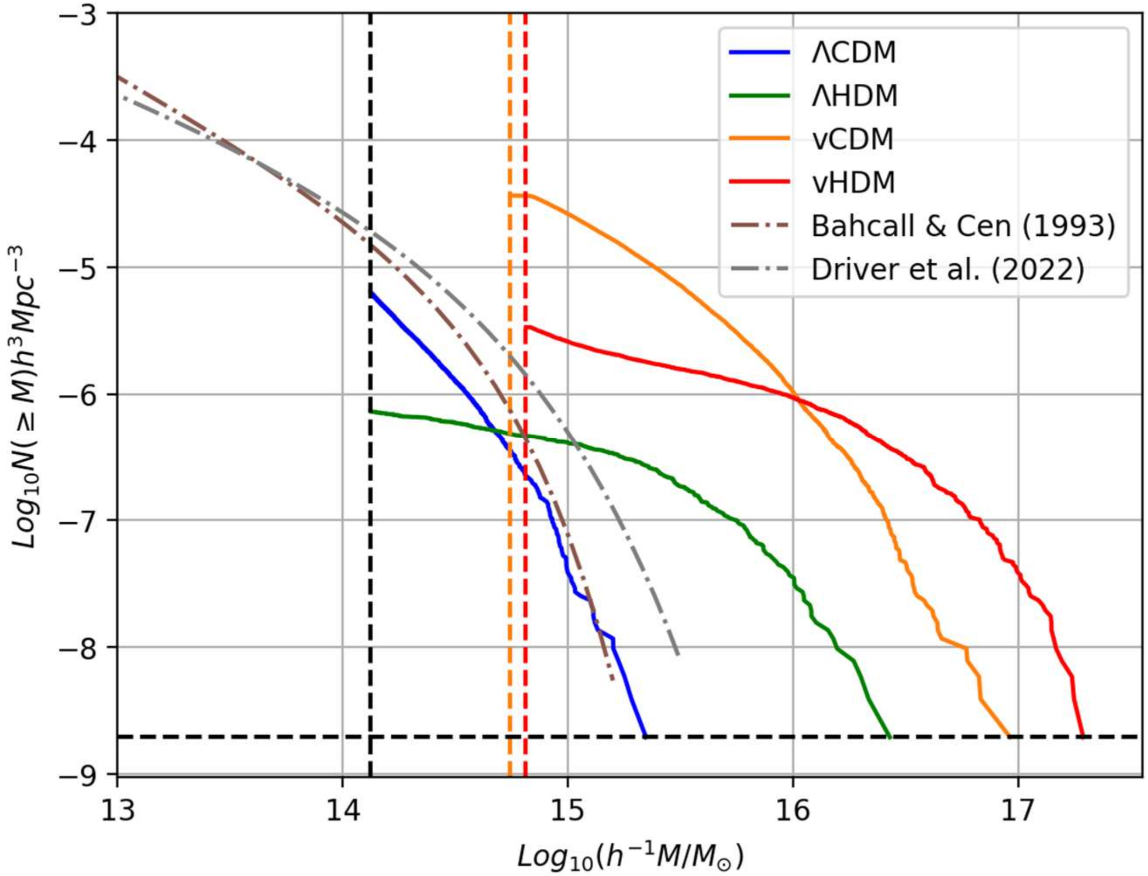
Runs presented here have 800 cMpc/h box length and 256^3 particles

Initialised at z=199 and initial conditions produced with CAMB and MUSIC (https://bitbucket.org/SrikanthTN/bonnpor/src/master/)

Consider ΛCDM, ΛHDM, νCDM and νHDM models for comparisons


ΛCDM
ΛHDM
νCDM
νHDM
x (cMpc/h)
y (cMpc/h)
$\rho_m/\bar{\rho}_m$
10^{-1}
10^{0}
10^{1}
−400 −300 −200 −100 0 100 200 300 400

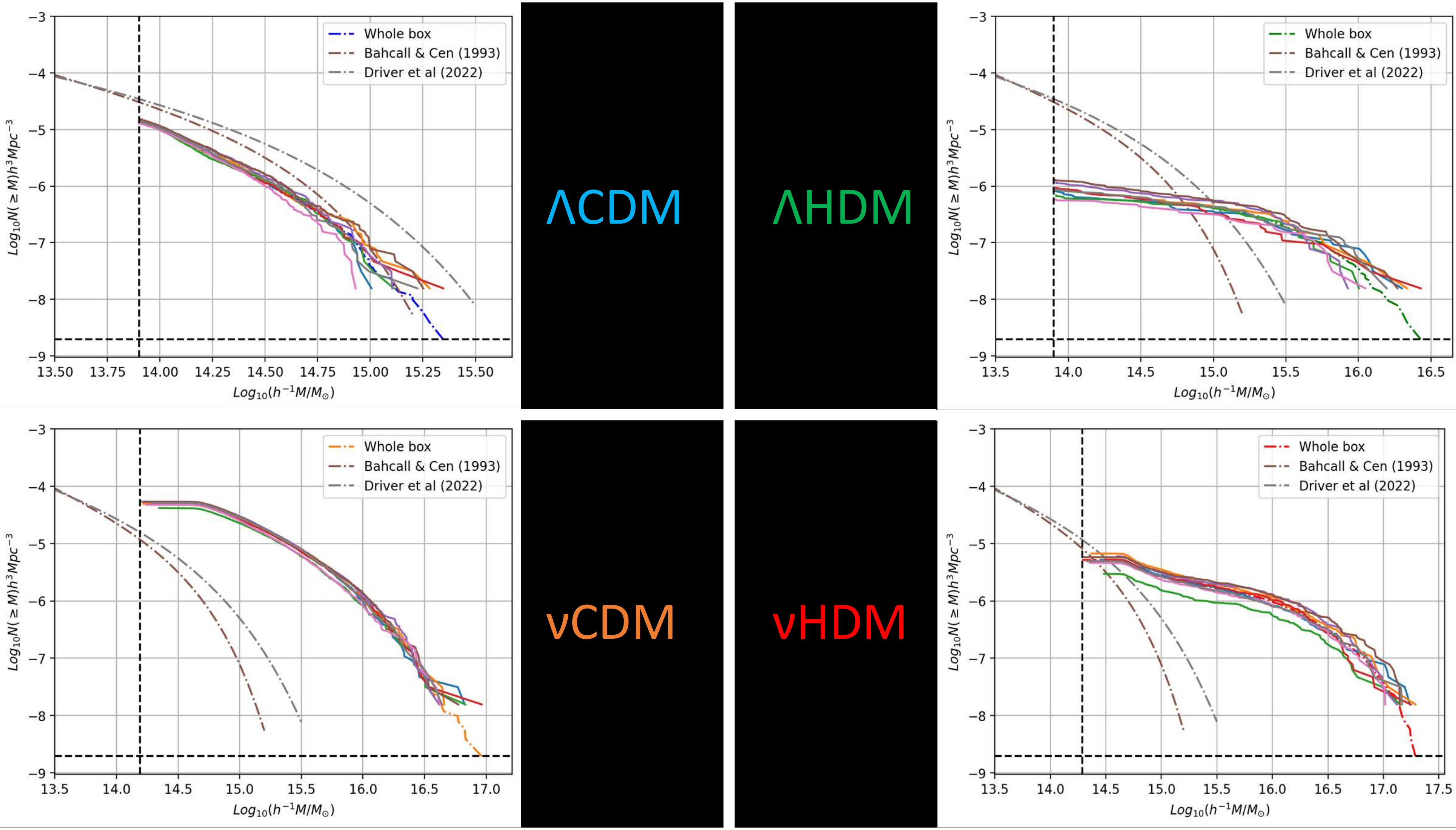
Cumulative Halo Mass Function

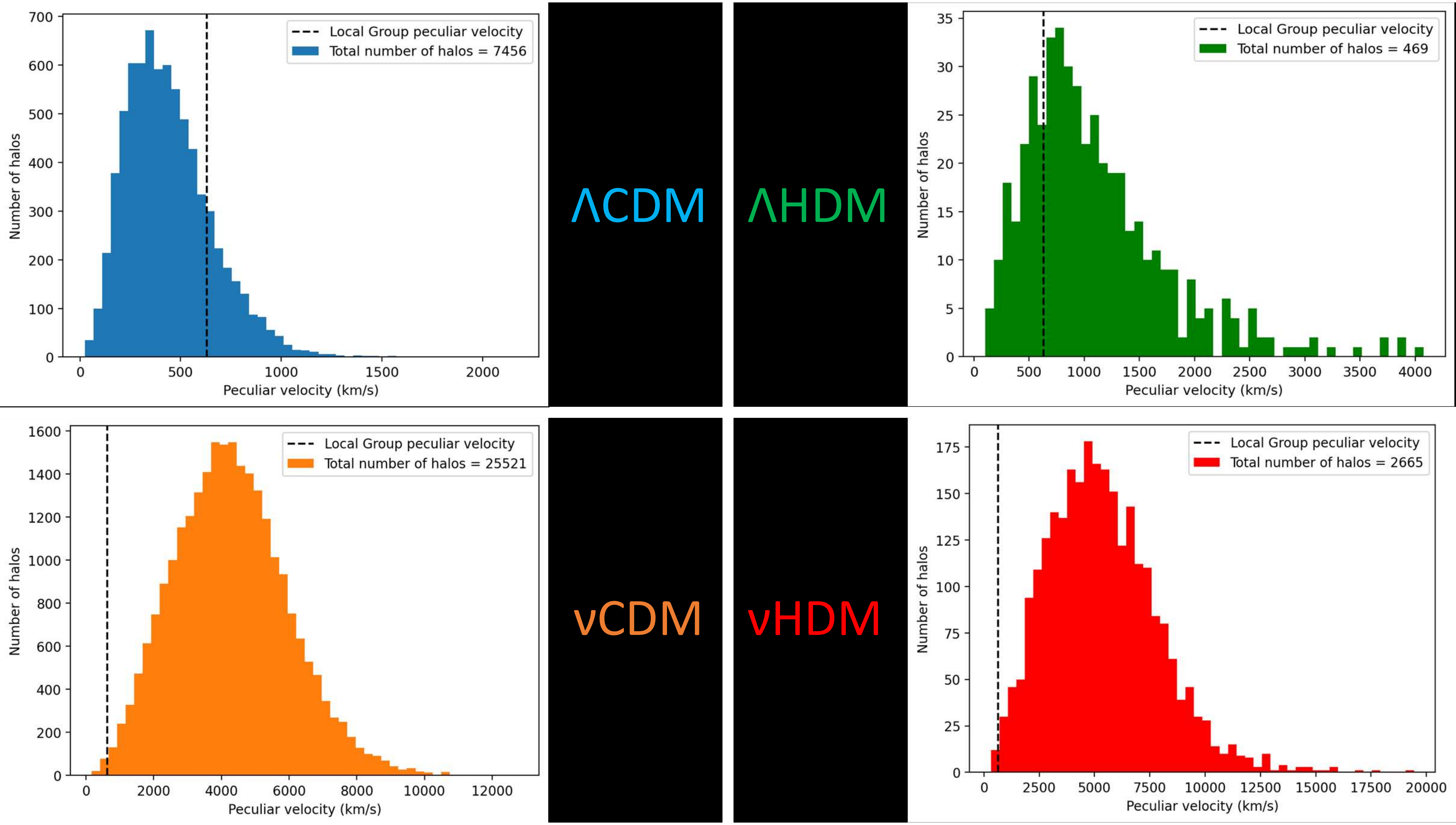


Halos identified with Amiga Halo Finder

$$M_{180} \equiv 180\rho_{crit}\left(\frac{4}{3}\pi R_{180}^3\right)$$

$$M_N = \nu\left(\frac{g_N}{a_0}\right)M_{180}$$


ΛCDM
ΛHDM
νCDM
νHDM
Whole box
Bahcall & Cen (1993)
Driver et al (2022)
$Log_{10}N(\geq M)h^3Mpc^{-3}$
$Log_{10}(h^{-1}M/M_{\odot})$


Local Group peculiar velocity
Total number of halos = 7456
Number of halos
Peculiar velocity (km/s)
ΛCDM
ΛHDM
Local Group peculiar velocity
Total number of halos = 469
Number of halos
Peculiar velocity (km/s)
Local Group peculiar velocity
Total number of halos = 25521
Number of halos
Peculiar velocity (km/s)
νCDM
νHDM
Local Group peculiar velocity
Total number of halos = 2665
Number of halos
Peculiar velocity (km/s)

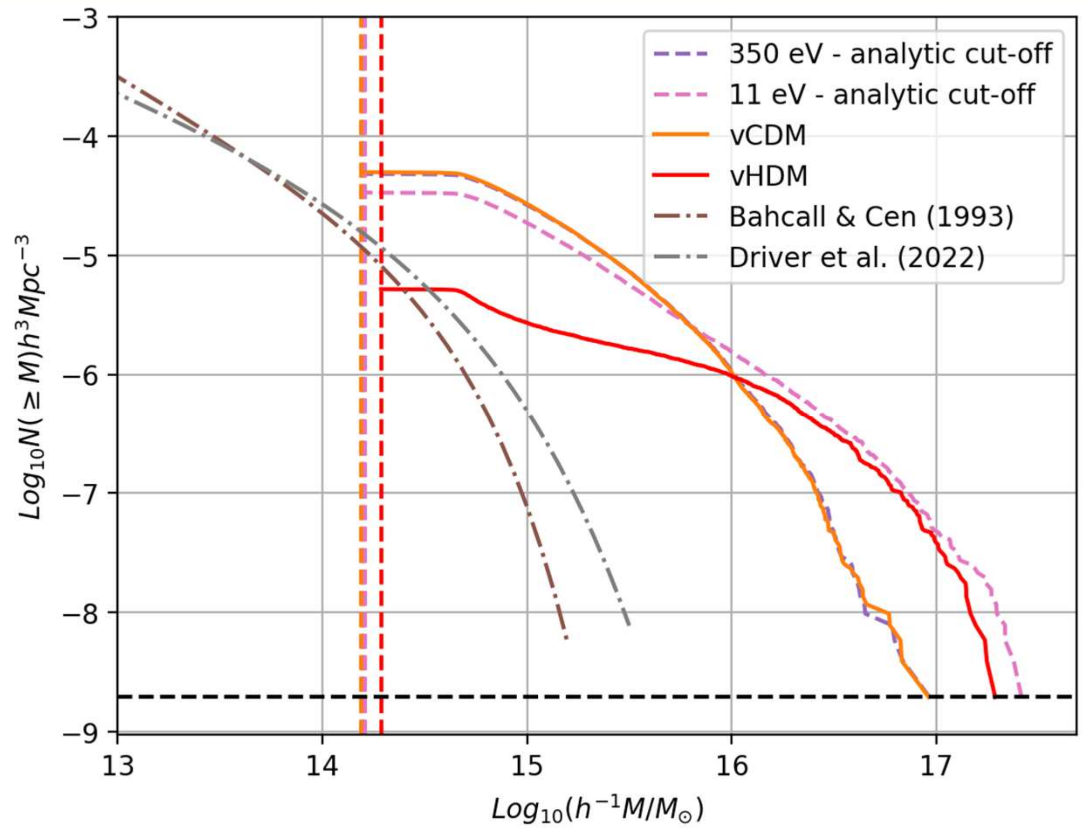
What next?

Creating a more realistic model

- Heavier sterile neutrinos
- Smaller enhancement to gravity

Analysis of Local Hole analogues

- What signals are imprinted onto mock observations?
- Can a Local Hole realistically solve the Hubble Tension?



Conclusions

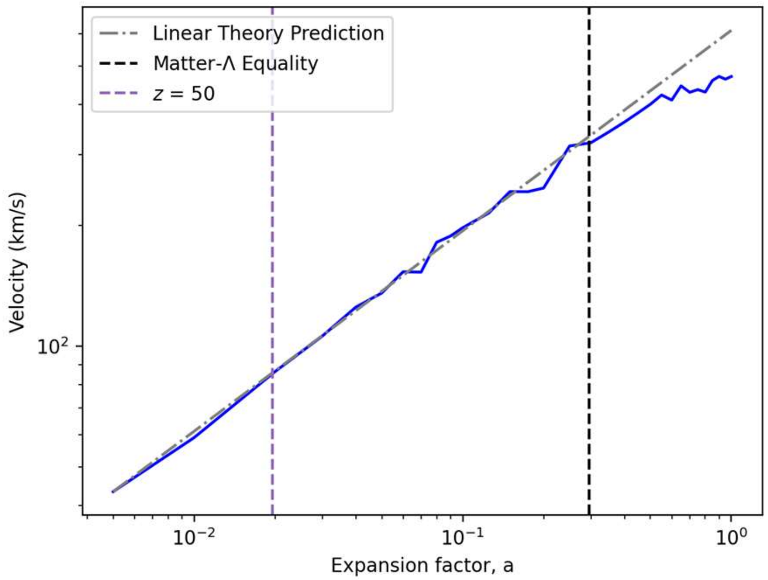
The νHDM cosmology does not ease large-scale tensions, but instead overcorrects

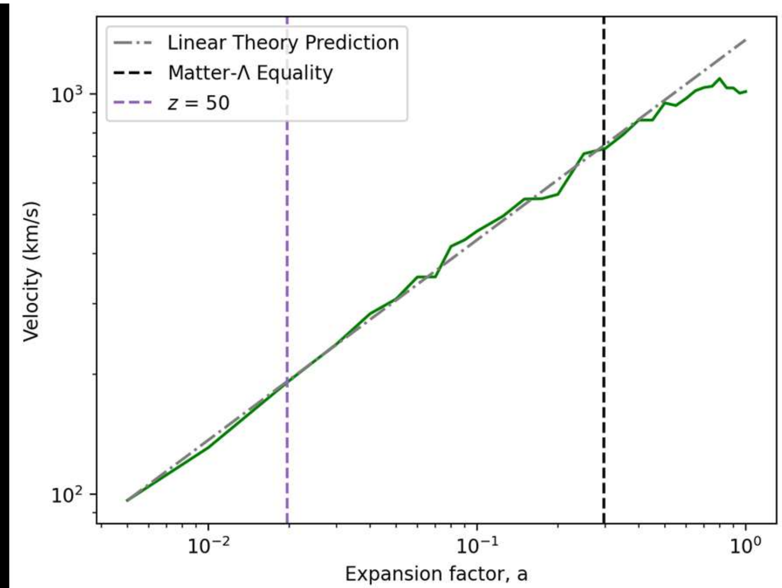
- MOND gravity **over-enhances** large-scale structure formation
- Hot Dark Matter **underproduces** small-scale structure
- A more realistic cosmology will require less drastic modifications

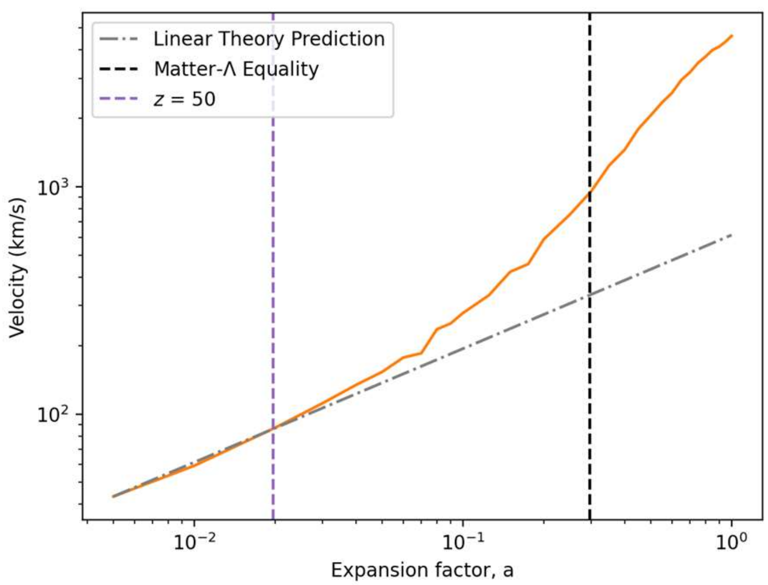
Supervoids produced in these self-consistent simulations can still provide insight into the real world

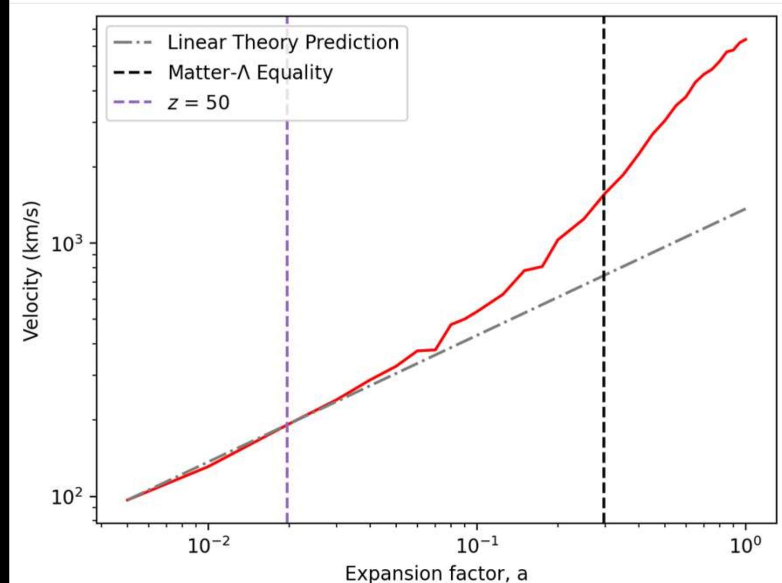
- What observational signatures should a local void produce?
- Do we observe these signatures and does the Local Hole really exist?
- Is a local void solution to the Hubble Tension plausible?

Appendix: Newtonian or not?

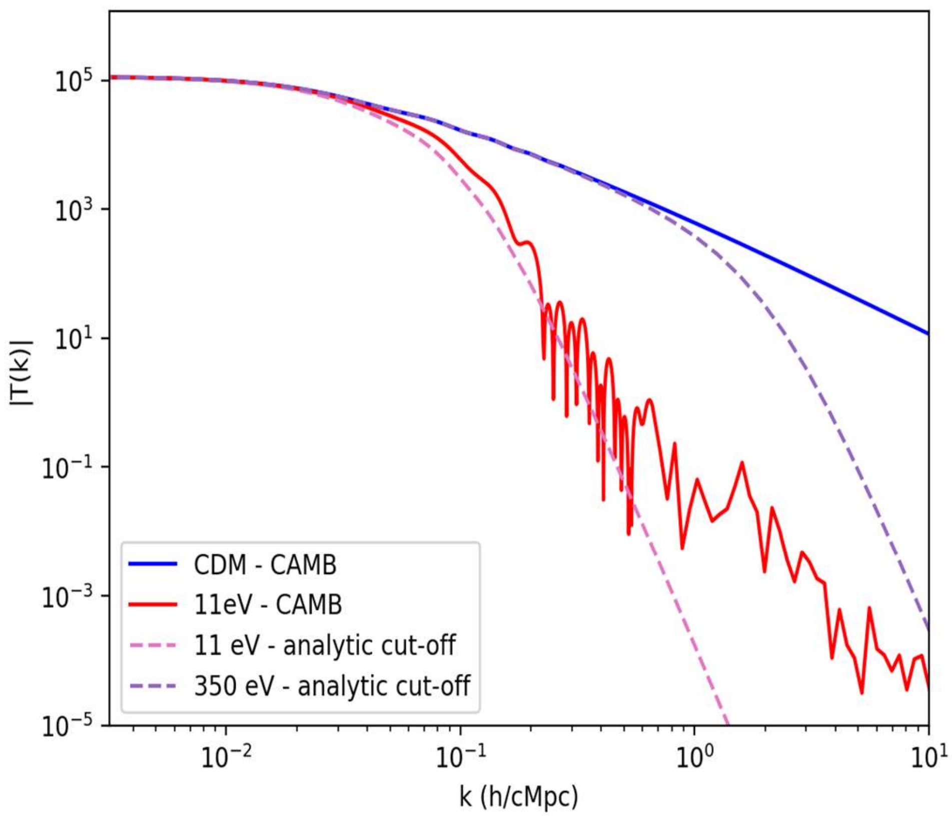


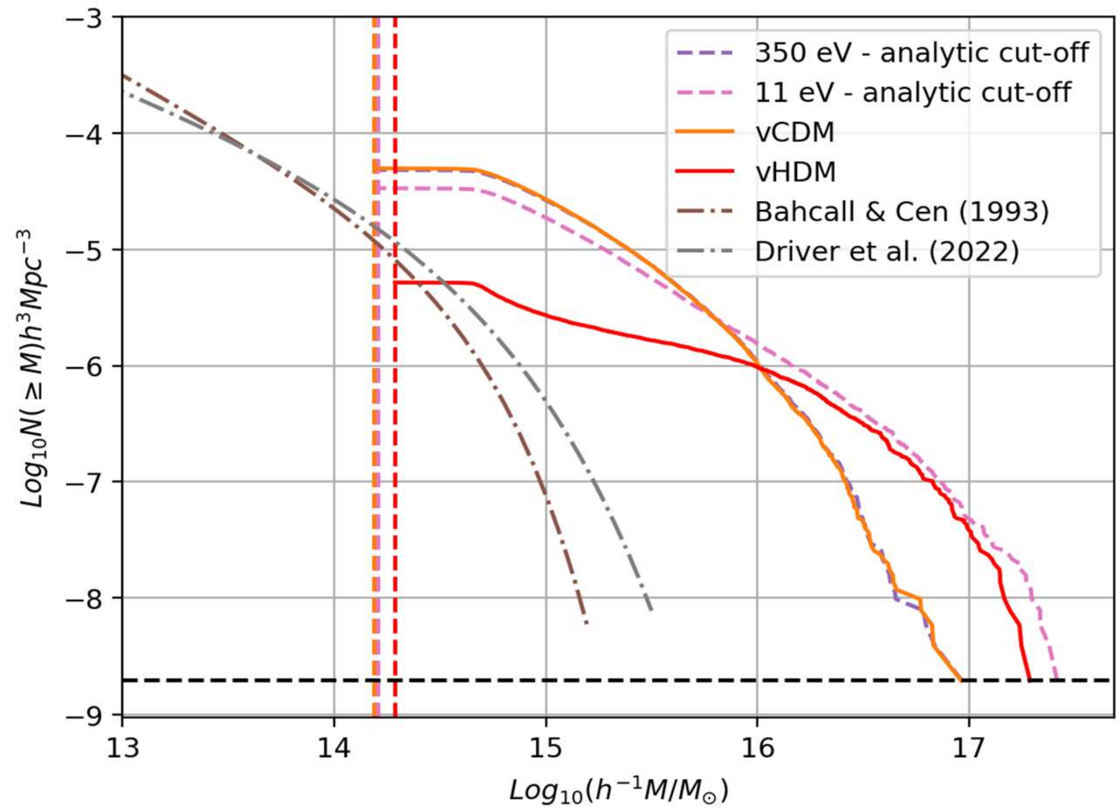




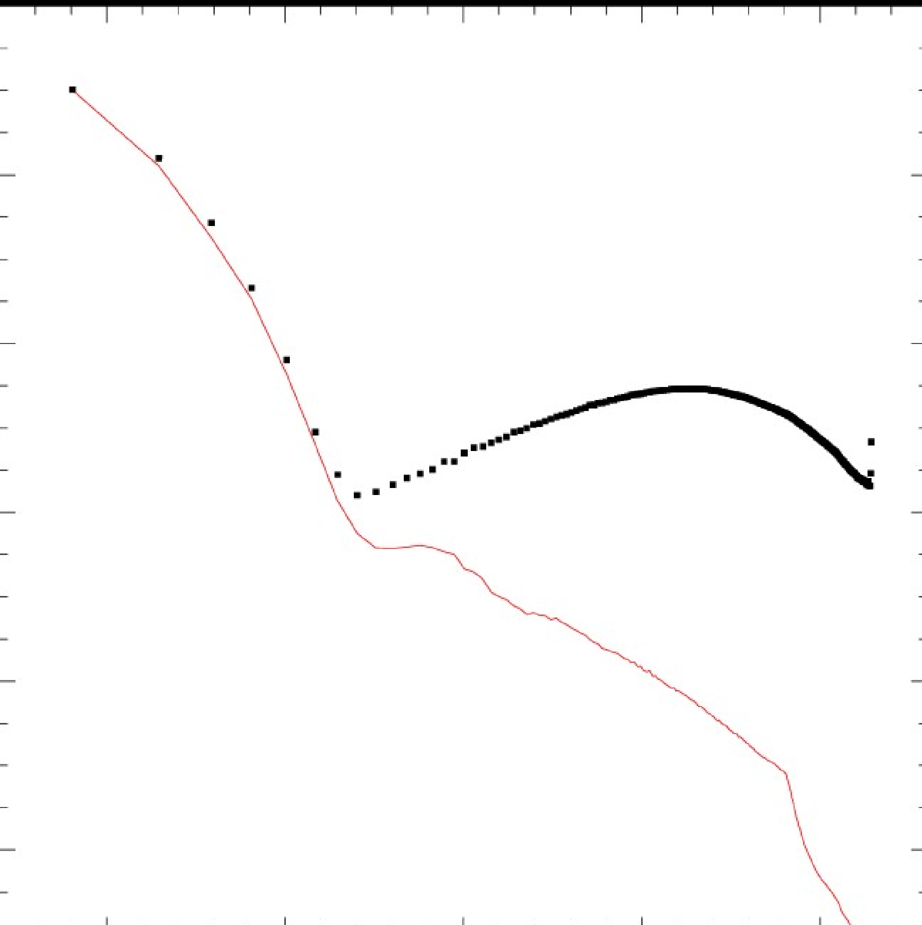


Appendix: Warm Dark Matter





Appendix: Resolution



Colín et al. 2008