A Rough Guide to Ruling Out CDM

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with Carlos Frenk and Adrian Jenkins

Contents

- N-Body Simulations
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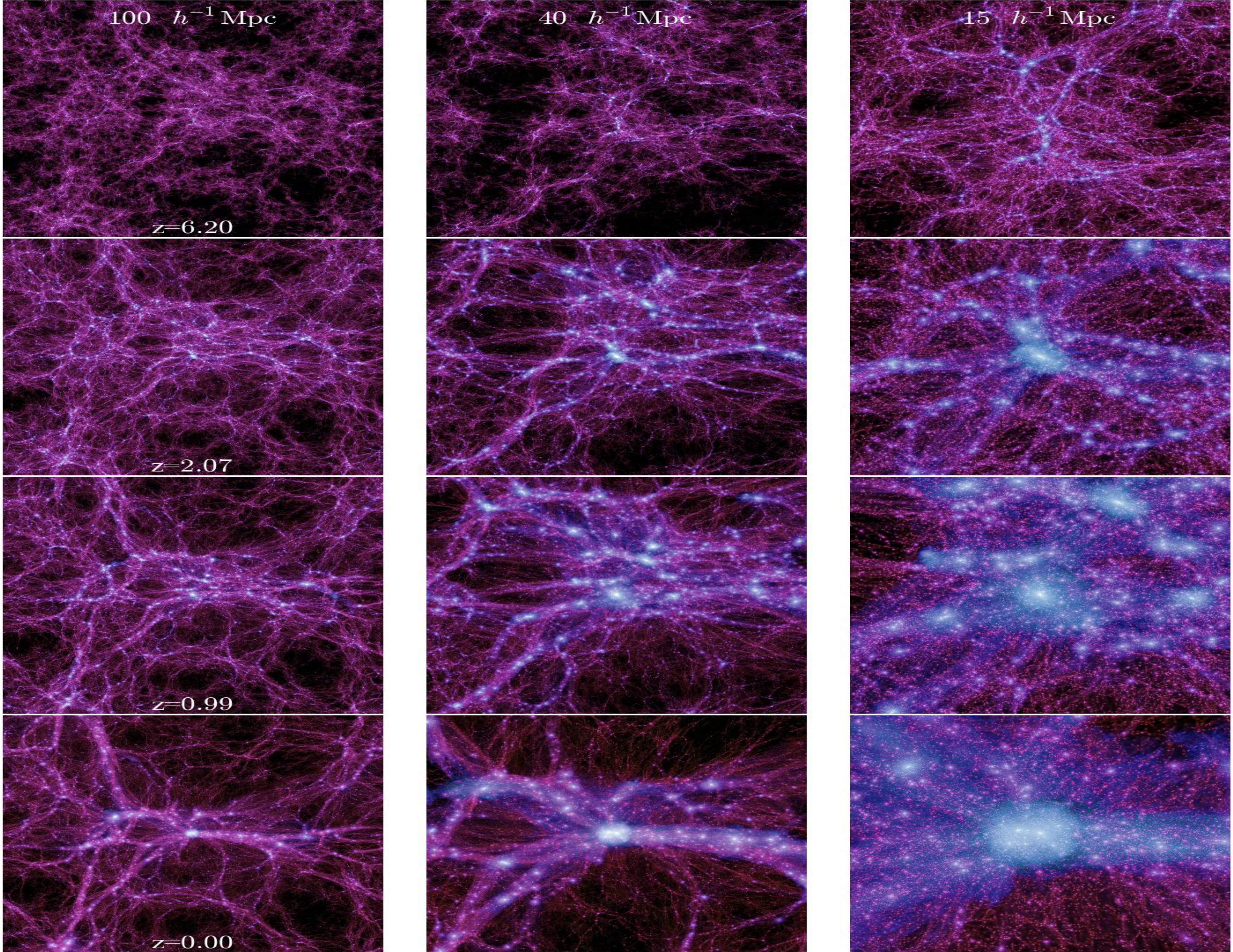
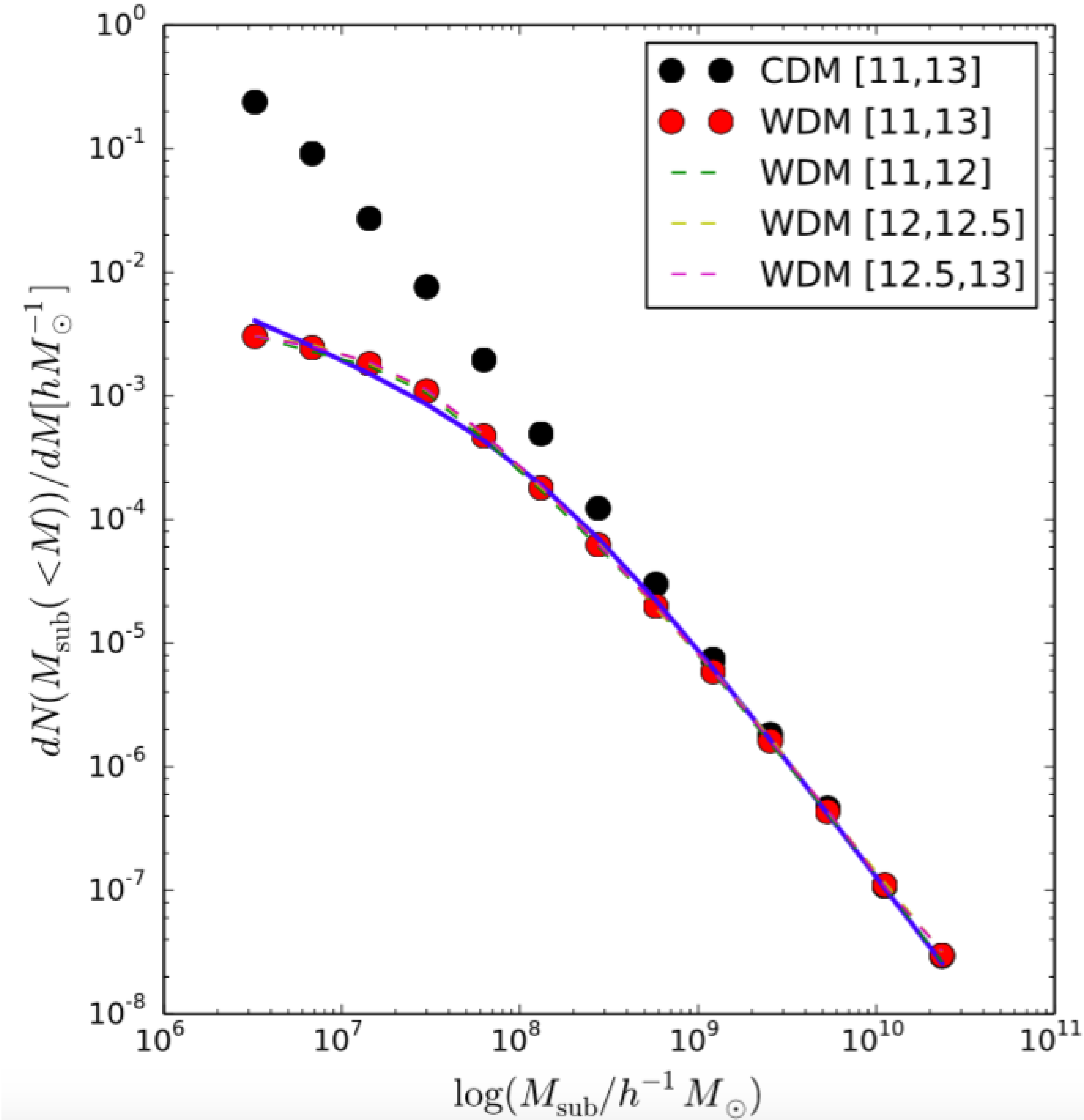
- The Future

N-Body Simulations

- Start with uniformly distributed particles
- Perturb them according to your dark matter theory
- Evolve them forward in time
- Analyse the structures that form to calculate observable quantities


100 h^{-1}Mpc
40 h^{-1}Mpc
15 h^{-1}Mpc
z=6.20
z=2.07
z=0.99
z=0.00



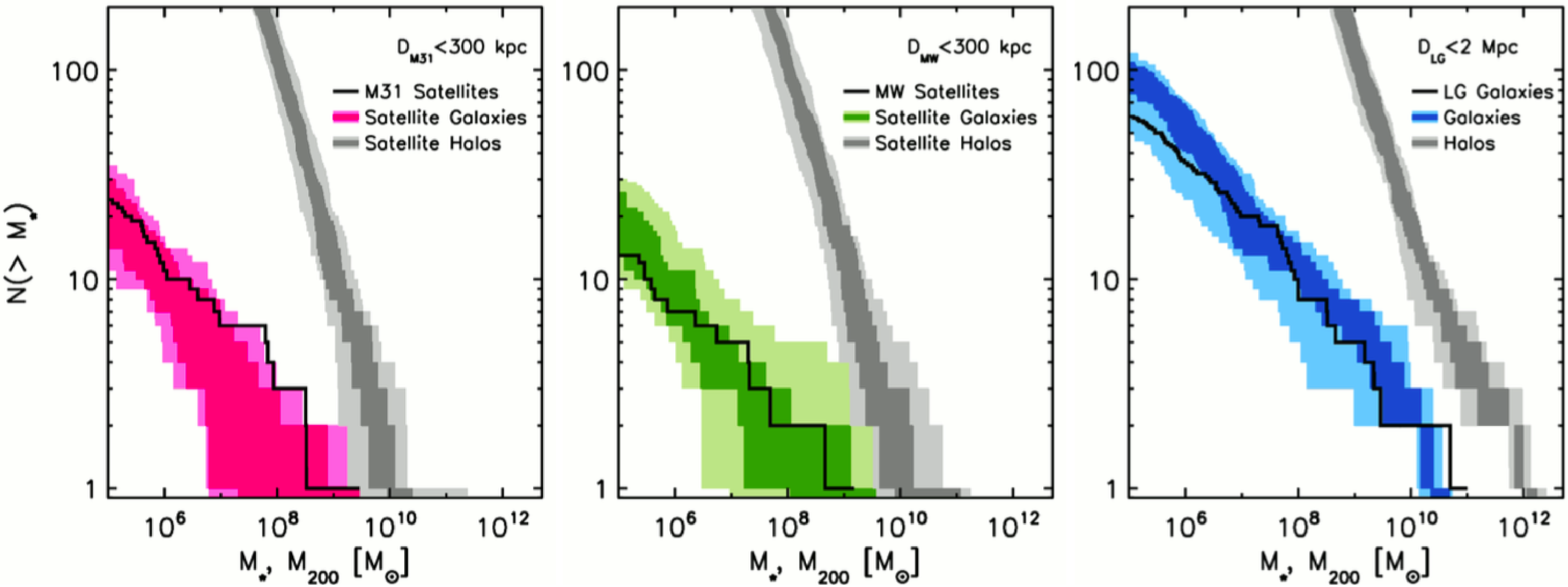
CDM [11,13]
WDM [11,13]
WDM [11,12]
WDM [12,12.5]
WDM [12.5,13]
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
$dN(M_{\rm sub}(<M))/dM[hM_\odot^{-1}]$
$\log(M_{\rm sub}/h^{-1}M_\odot)$

How to NOT Rule Out CDM

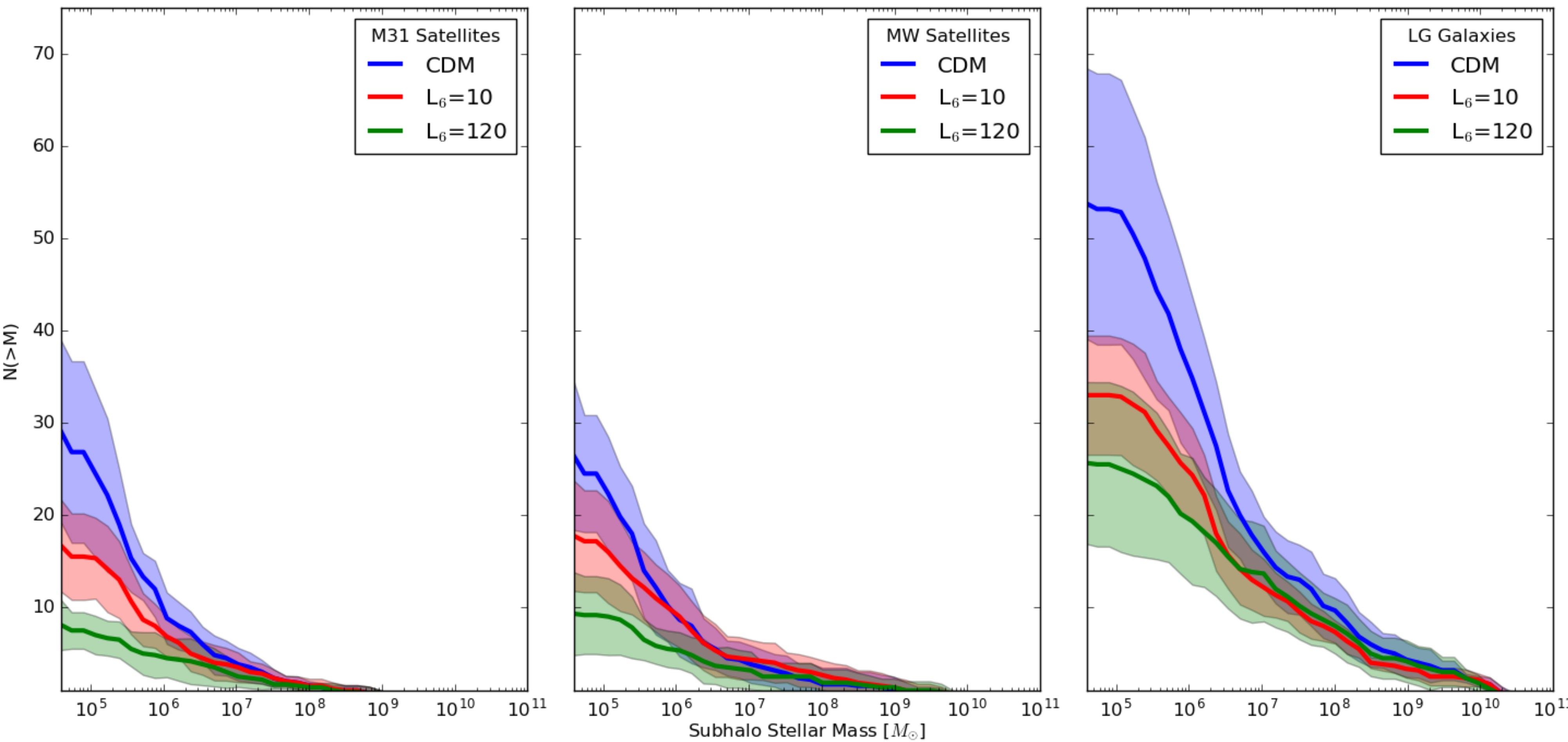
- Measure the masses of satellites in our galaxy
- Count how many are greater than a given mass
- If we don’t see enough, we can rule out CDM

The Small Scale Crisis in CDM

- Missing Satellites Problem
- Too Big To Fail Problem
- Core Cusp Problem
- Planes of Satellites



N(> M*)
100
10
1
10^6
10^8
10^10
10^12
M*, M200 [M⊙]
D_M31<300 kpc
M31 Satellites
Satellite Galaxies
Satellite Halos
D_MW<300 kpc
MW Satellites
Satellite Galaxies
Satellite Halos
D_LG<2 Mpc
LG Galaxies
Galaxies
Halos

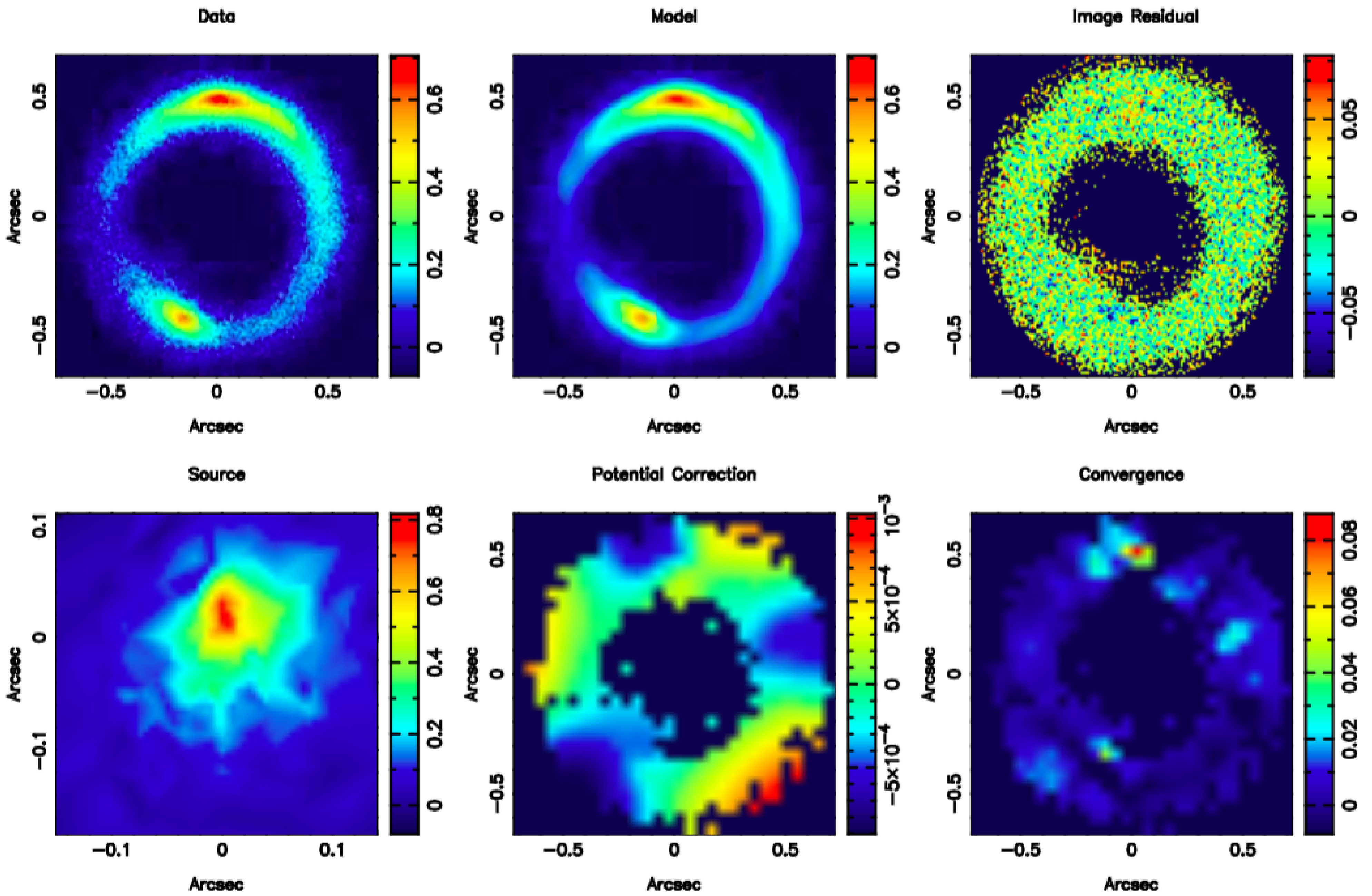

M31 Satellites
CDM
L6=10
L6=120
MW Satellites
LG Galaxies
N(>M)
Subhalo Stellar Mass [$M_\odot$]
70
60
50
40
30
20
10
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}


YOU
UNDERESTIMATE
THE POWER OF
THE DARK SIDE

Invisible Touches

- We want to observe objects with tiny or no stellar population
- Two promising methods
  - Gaps in stellar stream
  - Strong gravitational lensing - distortions in Einstein rings

Substructure and Einstein Rings

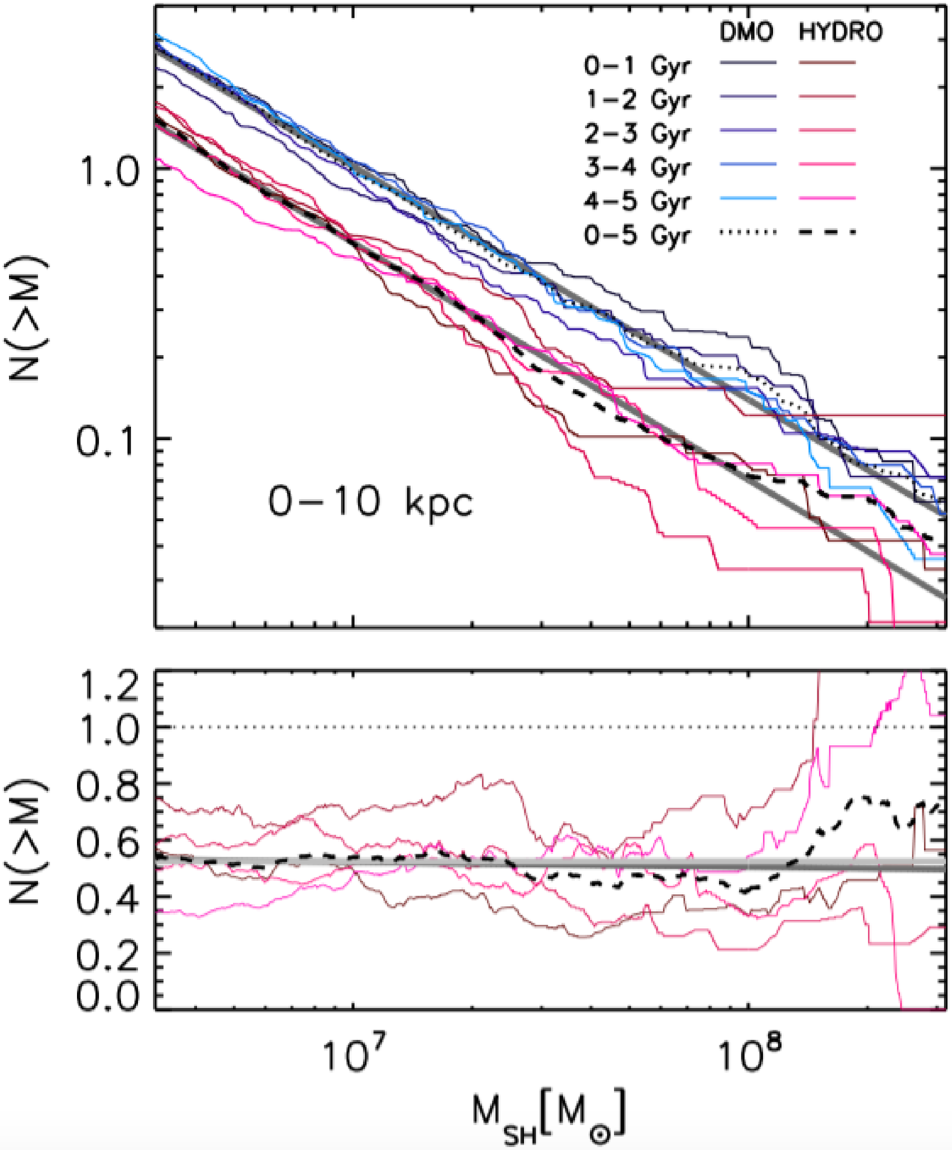


~100

Number of observations of strong lens systems to distinguish CDM from a 7kev sterile neutrino WDM system at the five sigma level.

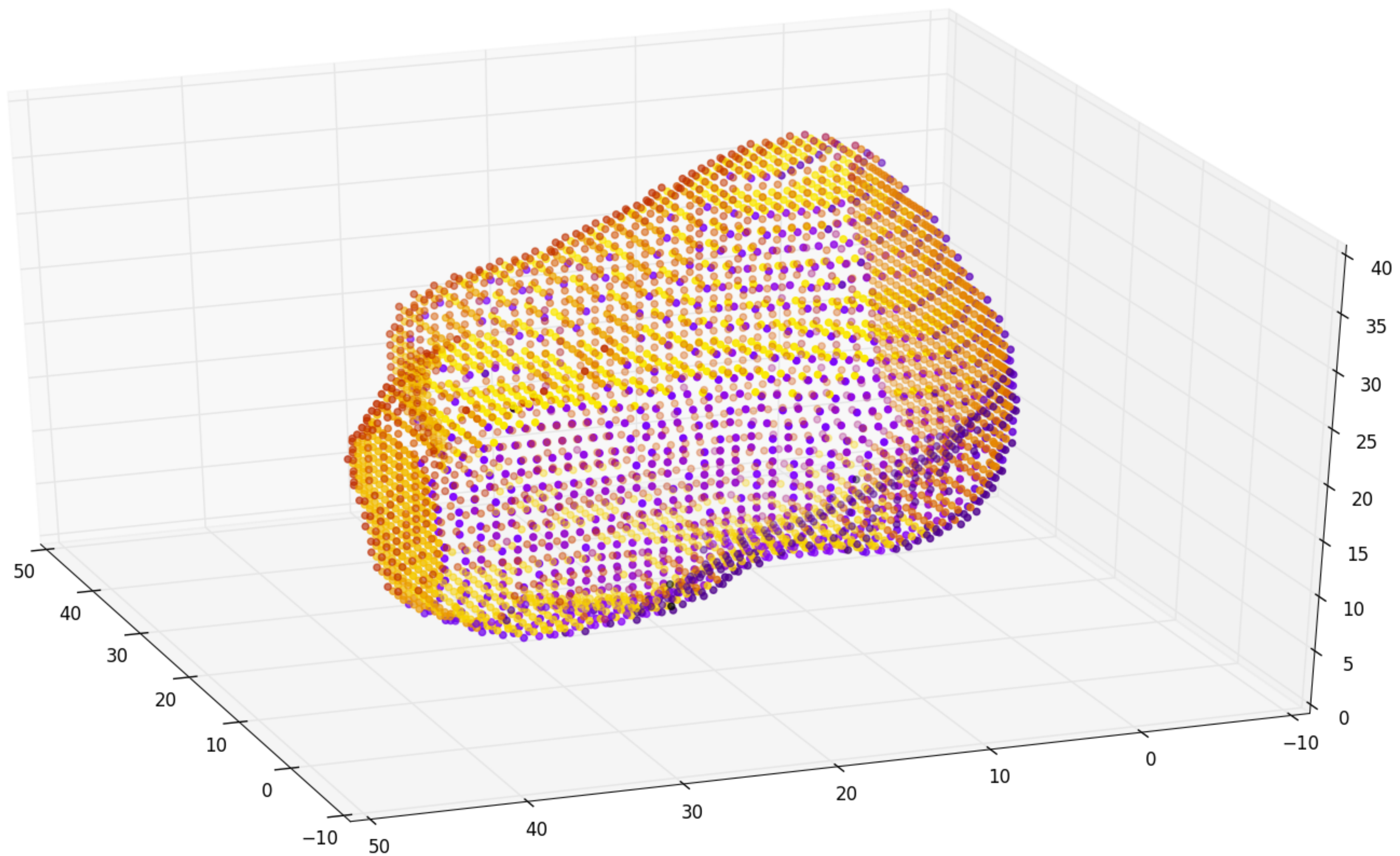
Simulating Massive Halos

- Need precise, unambiguous predictions to rule out CDM – requires full hydrodynamic simulation
- Huge dynamic mass range (6-7 orders of magnitude)
- Computationally extremely expensive

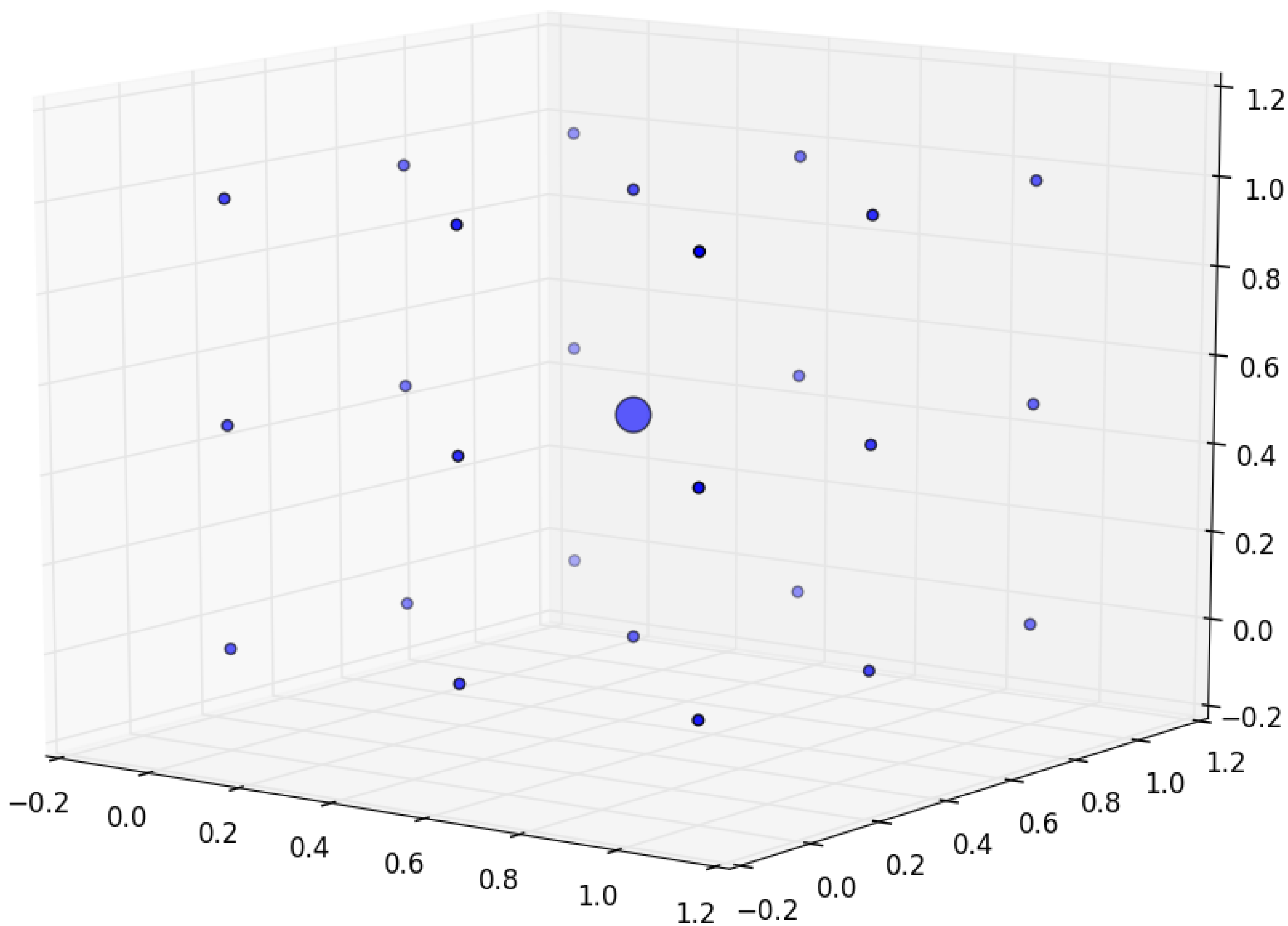


Baryon Destruction

Setting Up Initial Conditions Pt.1



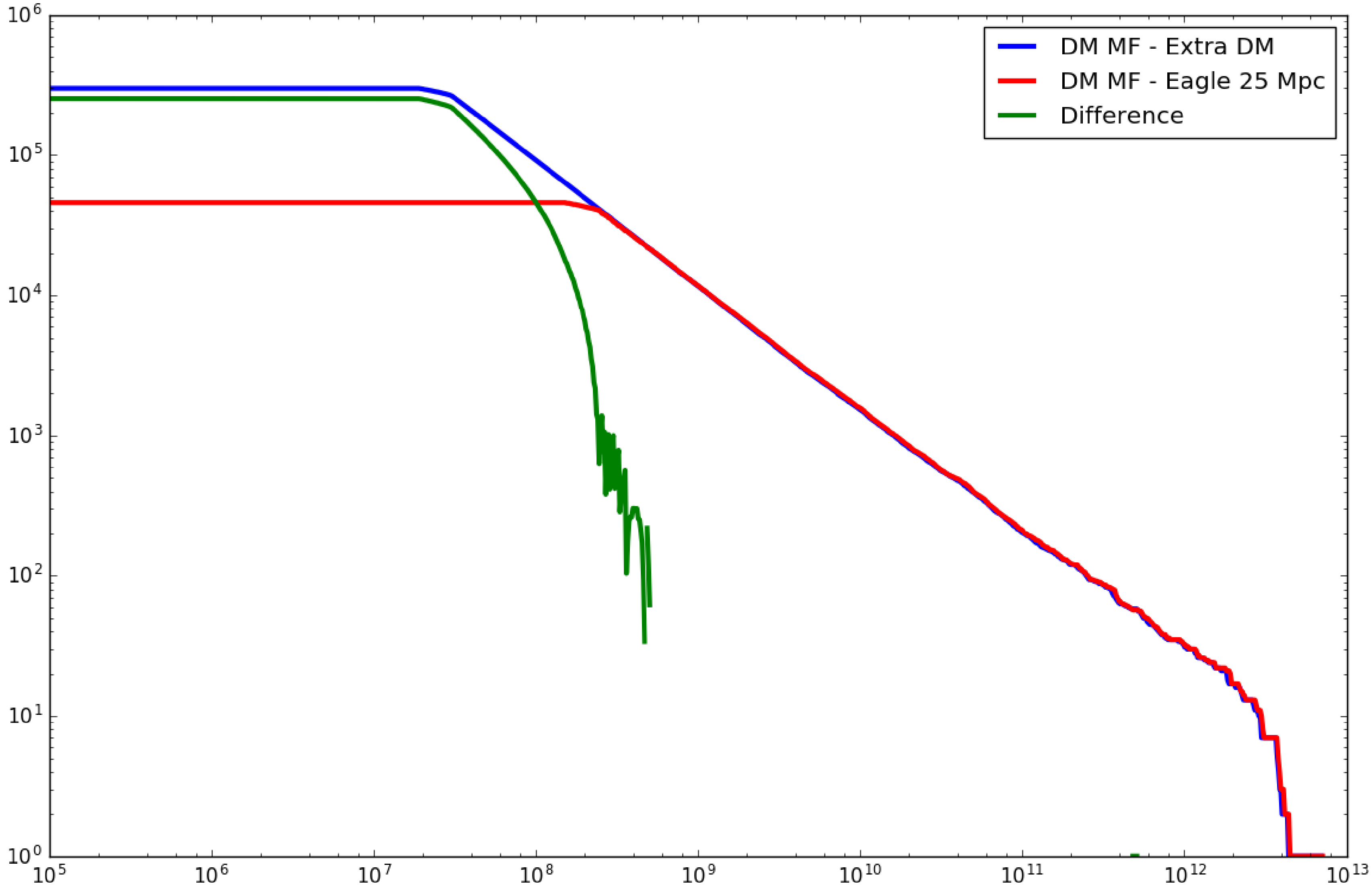
Setting Up Initial Conditions Pt.2

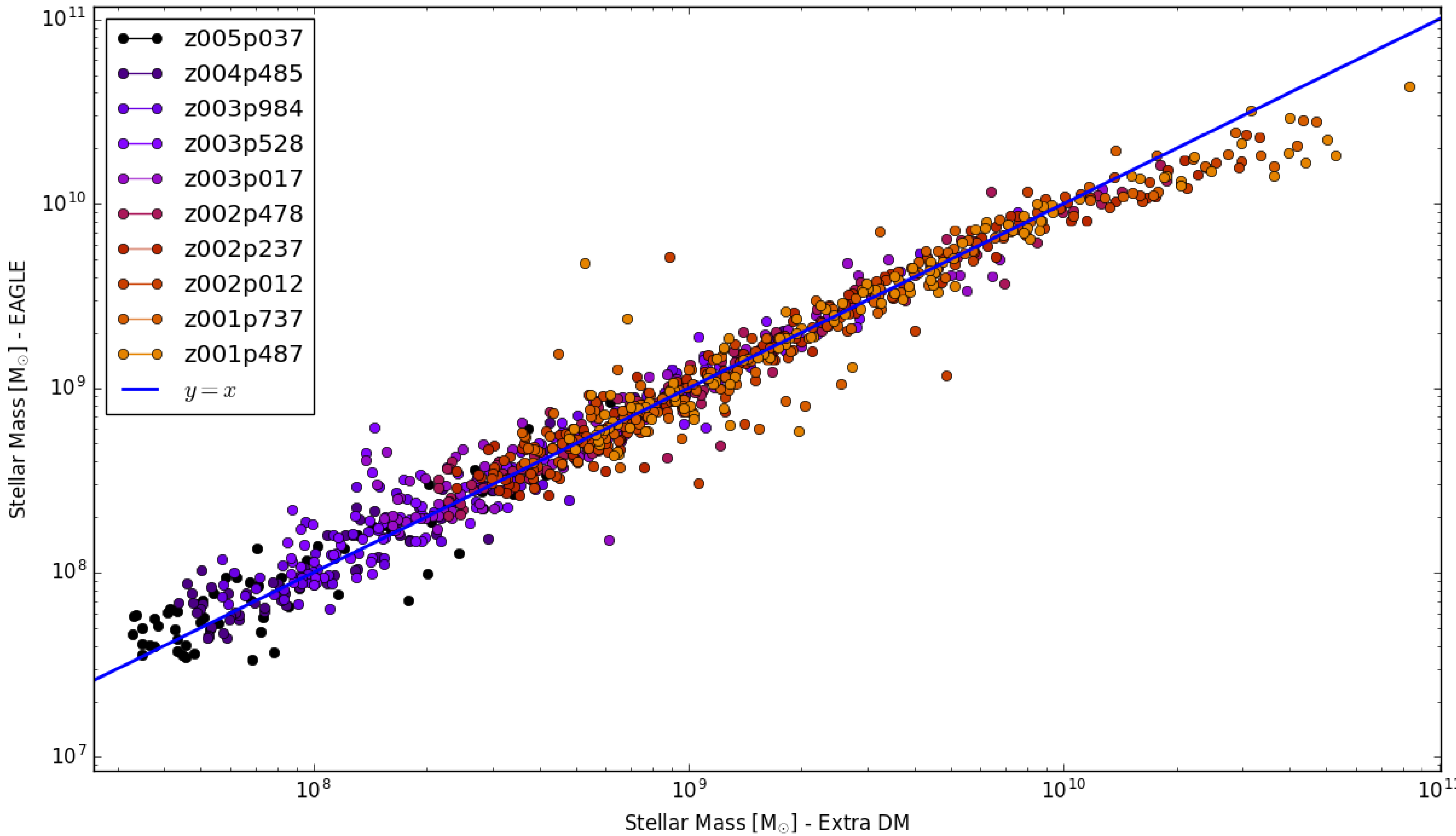


Effect on Resolution

- 7 DM particles for every SPH particle
- 25 Mpc box
  - SPH mass 1.2×10^5
  - DM Mass 9.38×10^4

- Goal : Apostle level 2 resolution in DM with approximately 960^3 particles


DM MF - Extra DM
DM MF - Eagle 25 Mpc
Difference
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}


z005p037
z004p485
z003p984
z003p528
z003p017
z002p478
z002p237
z002p012
z001p737
z001p487
$y = x$
Stellar Mass [$M_\odot$] - EAGLE
Stellar Mass [$M_\odot$] - Extra DM
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}

Summary

- Strong lensing allows us to probe the low end of the halo mass function.
- Upcoming observations, coupled with precise theoretical predictions can strongly constrain the nature of dark matter.
- Requisite predictions necessitate the development on new simulation techniques.

The Future

- Simulations must be analysed using ray-tracing codes to produce realistic mock obsrevations.
- Halos should also be simulated using alternative dark matter models to account for unexpected changes in baryon effects.